

California Water Plan - Update 2004

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ADVISORY COMMITTEE REVIEW DRAFT

Volume 4: Reference Guide

**Statewide Water Planning Branch
Department of Water Resources**

June 7, 2004

WORKING DRAFT of REPORT

The California Department of Water Resources has posted for review and comment an ADVISORY COMMITTEE REVIEW DRAFT of Volumes 1, 2, 3 and 4 of the California Water Plan – Update 2004. These files are also available electronically at web site address:

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The deadline for receiving comments on this AC Review Draft is:

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Introduction – Reference Guide

Volume 4 is the Reference Guide for the *California Water Plan Update 2004*. Many sources were used in preparing this Water Plan Update, and references meeting the following criteria are included in the Reference Guide:

- General reference material from prior California Water Plan updates.
- Articles prepared for, or in conjunction with, the California Water Plan that support material in Volume 1, 2 or 3.

Reference Guide articles are organized by topic and listed alphabetically within each topic. The nearly dozen topics are also listed alphabetically.

Author(s) and their affiliation are shown for each article. The authorship of articles written by DWR Project Team member(s) is indicated as staff.

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Future Food Production and Consumption in California Under Alternative Scenarios

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This report considers food production and consumption patterns in California in recent years and the likely pattern of California food production and consumption in year 2030. It also considers in less detail recent production and use of nonfood agricultural products. The purpose of this analysis is to help the California Department of Water Resources respond to legislative requirements concerning information used in considerations about future supply and demand for irrigation water in California.

Introduction

This report was prepared for the California Department of Water Resources (DWR) in its response to California legislation AB2587. A key phrase in the law is that “neither the state nor the nation should be allowed to become dependent upon a *net* import of foreign food.” In particular, DWR is urged to consider scenarios under which agricultural production in California is sufficient to assure that California is a net food exporter and that the net shipments out of state are enough to cover its traditional share of “table food” use in the United States plus “growth in export markets.”

The law is specified in terms of aggregate food production, consumption and trade on a net basis. The focus on feeding the population in California and “table food” for the United States excludes several of the most important agricultural commodities in California. In particular, cotton and ornamental crops are not food items, but both are important in production value. Cotton ranks second in export value, and ornamental horticulture crops, as a group, generate about \$3 billion in farm production value in California. Furthermore, the analysis and projections to consider “net import of foreign food” exclude such livestock feed crops as hay, feed grains and oilseeds.

The main focus of the legislation was on concerns for water available for food production in California relative to food use in California. Consistent with this emphasis, nonfood crops are not included in our full analysis of production and use currently or in 2030. However, we do examine the position of California with regard to ornamental horticulture, cotton, live animals and animal feeds. We note that California uses far more animal feed and more cotton (in the form of clothing and textiles) than it produces, but it is a net shipper of ornamental horticulture, mainly to other states.

The reference to food consumption, production and trade requires a common unit to aggregate the individual food commodities. (It is useless to attempt to create food balances for hundreds of individual commodities. Even if this were feasible, the questions we are addressing and AB 2587 relate to California food as a whole and not to specific products.) Given the nature of food production in California, the only

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reasonable unit for aggregation is the value of each commodity. Aggregation in value terms reflects the relative weights of these commodities from the viewpoint of buyers. It makes no sense to simply add tons of apples and tons of oranges or tons of rice and tons of Cabernet Sauvignon. In some very poor countries, analysis of food supply and demand is done in terms of staple-grain equivalents, where basic foods are converted to equivalents of tons of rice or wheat. Such an approach may be useful, for example, in North Korea, but makes no sense in California, where dairy, beef and horticultural crops dominate food production. We therefore use estimates of the farm value production, consumption, and trade of food products to calculate the net trade position of California.

Measured by aggregate value, California is a net food shipper to the rest of the United States and the rest of the world. Besides shipments out of state, there are substantial gross shipments of food and other agricultural products into California. California food shipments from the rest of the United States and from international sources are large and vital to the health and welfare of Californians. Furthermore, imports of such nonfood agricultural commodities as live animals, livestock feed, and crop seed are also crucial to the productivity of California food industries. The net export trade balance must not obscure the importance of trade flows in both directions.

This analysis does not consider the nutritional details of available food. We aggregate across food products using values rather than a single nutritional unit such as calories or vitamins. A far more extensive analysis would be needed to consider the trade position of California for each major nutrient component.

Furthermore, we only consider net shipments of food into and out of California. Most food consumed in the state, including grain products, meat, tropical fruits, and “off-season” produce is produced elsewhere, and most of the crop production in California, although not the dairy production, is shipped out of the state. We follow the specific language of AB 2587 in examining net trade flows.

Turning to the supply side, we do not attempt to decompose expected crop yield growth due to aggregate technological improvement adopted in California into specific technological changes. It is very difficult to forecast the rate at which new technologies will be adopted and essentially impossible to project the path of applicable research itself. Such crop yield improvements have occurred steadily for decades, but we have not attempted to project which innovations will be adopted over the next three decades.

We do not explicitly consider irrigation water supply or demand. As specified below, we do consider a reduction of overall cropland with a shift to urbanization. This implies a shift of the irrigation water now associated with that cropland. Our analysis does not explicitly model changes in the current irrigation water situation. For example, we do not estimate the state of snow packs or reservoir levels. Nor do we explicitly consider the position of ground water availability into the future. Our analysis implicitly holds irrigation water use per unit of cropland constant. We incorporate explicit growth in output per unit of land. This implies growth in output per unit of irrigation water, but we do not include any further reduction in irrigation water use per unit of land. There have been declines in water use per acre in California for many crops, but we, conservatively, do not project those to continue.

Section 1. Interpretations and Analysis of Current Data

We first calculated the current position of California food consumption, production, net shipments to the rest of the United States, and net shipments to export markets. Table 1 shows approximate values for five food categories and for the sum of those commodities. The food categories include approximations for most of U.S. food and beverage production and consumption. We exclude some processed product trade and some minor food items. We also do not include fish consumption.

Base Data and Methods

The first step was to determine a base period for California production. The California production data used was reported in the 2002 CDFA Resource Directory, which lists California production data for 2001 that is taken from data produced by the National Agricultural Statistics Service (NASS) of USDA. In 2001, California vegetable production was valued at \$6.1 billion, and California fruit and tree-nut production was valued at \$7.0 billion, for a combined value of \$13.1 billion. The next category “Food Grains” is comprised of rice and wheat. The 2001 value for wheat was \$112 million. The 2001 production value of \$138 million reported for rice in the 2002 CDFA Resource Directory was inconsistent with other reports, so we used the \$203 million value of production figure reported directly by the California office of the National Agricultural Statistical Service (CASS). Combining the rice and wheat values yielded a \$315 million value of production for food grains. The value of production of milk and cream was \$4.63 billion in 2001. Remaining livestock (primarily beef) and poultry (including eggs) totaled \$2.72 billion in 2001. Other food products, including oilseeds, sugar and sweeteners, and spices totaled \$103 million in 2001. Thus, the total value of California food production in 2001 was \$20.5 billion at farm gate value.

Next, we turned to consumption for 2001. We obtained the total U.S. consumption for the five categories by adding the value of U.S. imports of goods for each category to the value of U.S. production of goods for each category and then subtracting the value of exports of the goods from each category.

Data for the value of U.S. production was obtained from the NASS. For example, U.S. food grain (wheat and rice) production value totaled \$6.37 billion in 2001 (\$5.44 billion for wheat and \$925 million for rice). Trade data for the United States is based on the Foreign Agricultural Service’s FATUS database. According to these data, the United States exported \$4.02 billion worth of food grains (\$3.33 billion for wheat, unmilled and \$692 million for rice, paddy) in 2001. At the same time, the United States imported \$450 million worth of food grains (\$169 million for rice and \$281 million for wheat). The production values here are at the farm gate. The trade data are at port and, therefore, includes some post-farm value added. The estimate of post-farm gate value added varies widely across products (Bervejillo and Sumner). Unfortunately, there are no estimates available of farm value of imports or exports.

Applying the formula for consumption (production + imports – exports), we obtained a \$2.8 billion total for U.S. consumption of food grains in 2001. Using similar procedures, U.S. consumption for fruit, tree nuts and vegetables was \$29.4 billion in 2001. Milk and cream consumption in the United States was \$25.5 billion, livestock and poultry consumption totaled \$72 billion, and other food product consumption was \$10.2 billion. Total U.S. consumption of food commodities was approximately \$140 billion in 2001.

Because California data was unavailable, California consumption was derived from U.S. consumption data using the approximate California share (12 percent) of the national population. At the level of

precision available for other parameters and estimates, this approximation is appropriate. We assumed that consumption patterns in California were similar to those in the rest of the United States. California population in 2000 totaled about 34 million, and the U.S. population was about 282 million. Applying 12 percent to total U.S. consumption of the individual commodity groupings yielded a California consumption figure of \$3.5 billion for fruits, tree nuts and vegetables, \$338 million for food grains, \$3.1 billion for milk and cream (dairy) products, \$8.6 billion for livestock and poultry, and \$1.2 billion for other food products. Total California consumption of food commodities totaled \$16.8 billion in 2001.

The USDA Economic research service (Lin et al.,) provide detailed analysis of how per capita consumption of food differs across the United States by region, ethnicity and other demographic factors. In addition, we could have made adjustments for the slightly higher average personal income in California and for differences in relative prices. We found in our preliminary analysis that none of these adjustments was large for food aggregates and some were offsetting, so we expect the consumption figures that we calculated are close to the true, but unavailable, figures. Notice that all these calculations are done on a farm value basis or port value for imports and exports and do not include the value of the farm-to-retail markup. For the livestock data, we have taken into account that meat animals are often exchanged in farm-to-farm transactions before the final sale to food processors.

Next, we looked at California trade. Export data was obtained from the AIC database on California's agricultural exports. Given the base data on exports we used export values that included some value that was added after the product left the farm. Rice exports in 2001, for example, totaled \$166.4 million, and California wheat exports were valued at \$3.9 million. Thus, the total for the food grain category was \$170.3 million. Export figures were also obtained for the other food categories in the study. Note that California does not export food commodities included in the category "other food products." Vegetable oils, peanuts, sugar and sweeteners, and spices are mainly produced in other parts of the United States or not produced in the United States at all.

There is no database for imports by state in the United States, but data are available for the nation as a whole (see above). To get a reasonable approximation of California imports of food commodities, we again applied the 12 percent population share. Taking the example of food grains, we estimated that the California value of such imports for 2001 was \$54 million (12 percent of \$450 million in U.S. food grain imports). We derived California import values for the other food commodity categories in the same manner.

Base Position of California Food Production, Consumption of Trade in 2001

From the production and consumption values for food commodities in California, we can derive the net position of California agriculture. Subtracting California consumption from California production yields the value of California production available for consumption in the rest of the United States or for international export. These data are reported in Table 1. As expected, California was a net exporter of fruit, tree nuts and vegetables (\$9.6 billion), a net importer of food grains (\$25 million), a net exporter of dairy products (\$1.6 billion) and a net importer of livestock and poultry (\$6.3 billion) and other food products (\$1.1 billion). For food commodity production, California was a net exporter by \$3.6 billion in 2001.

Now consider the net trade position of California food commodities with the rest of the world. California was a net exporter of \$2.5 billion in fruit, tree nuts and vegetables to the rest of the world in 2001. California food grains and the dairy industries also had net foreign trade surpluses in 2001. California, however, is a net importer of livestock and poultry and other food products.

After obtaining California's net position regarding the production and trade of food commodities, we were able to derive the net trade position of California with the rest of the United States by subtracting California net trade with the rest of the world from California's net production (production minus consumption). The results are in the last row of Table 1. The second to last row in Table 1 shows U.S. consumption minus California consumption.

The first three rows of Table 1 show the production, consumption and net surplus position of California for each of the food categories. Row one shows the value of California production of each food category. And a total production value of just over \$20 billion. This is a probably a small overstatement of California's food production value because it includes the value of hides and skins and wool. As noted above, California consumption values are approximated by assuming that California consumes 12 percent of the national total disappearance of each category (based on California's share of national population).

The international export position of California agriculture is shown in the rows 4–6 of table 1. Most food exports are in the fruit, tree nuts and vegetables category, and because of the large export surplus in this category, California is a net exporter of food value.

To consider the position of California relative to the food consumption of the rest of the United States outside California and to the United States as a whole, we estimated the farm value of U.S. food consumption and the farm value of U.S. food consumption outside California (RoUS). Total farm value of U.S. food consumption at is about \$140 billion, with about 12 percent (\$16.8 billion) of that in California. California production of food accounts for about 14.6 percent of total U.S. food consumption (\$20.5 billion California production/\$140 billion U.S. consumption) and about 14.4 percent of U.S. food production (\$20.5 billion California production/\$142.5 billion U.S. production). On a net basis, California production could cover California consumption plus another 2.6 percent of food consumption in other states.

California exports valued at the port equal about 21 percent of food production valued at the farm. The AIC estimate is that California exports average about 18 percent of the production by quantity for 50 main export commodities (Bervejillo and Sumner 2003). Thus, their estimate is that on average port value is about 16.7 percent higher than farm value for the main California export products. We estimate that international imports are about 14 percent of food consumption in California.

Also note the 14.6 percent share of California production in U.S. food consumption at farm (or import) value is higher than California's share of U.S. agricultural production overall because California produces relatively little feed crop value, no tobacco, and a small share of energy crops (mainly corn for ethanol). California is a net exporter of food to the rest of the world on a net basis.

Table 1
Farm Value and Border Values of Food Commodity Production, Consumption
and Trade for California and the United States, 2001, in Million Dollars

| | Fruit, tree nuts, vegetables | Food grains (rice and wheat) | Dairy | Livestock and poultry | Other food products¹ | Total² |
|---|---|---|--------------|----------------------------------|--|--------------------------|
| Calif. production | 13,100 | 313 | 4,630 | 2,300 | 103 | 20,446 |
| Calif. consumption ² | 3,527 | 338 | 3,061 | 8,643 | 1,233 | 16,802 |
| Production – consumption | 9,573 | -25 | 1,569 | -6,343 | -1,130 | 3,644 |
| Calif. RoW ³ exports | 3,658 | 170 | 340 | 180 | 0 | 4,348 |
| Calif. RoW imports | 1,176 | 55 | 207 | 516 | 430 | 2,384 |
| Net Calif. with RoW trade | 2,482 | 115 | 133 | -336 | -430 | 1,964 |
| Total US consumption ⁵ | 29,394 | 2,820 | 25,507 | 72,023 | 10,279 | 140,023 |
| RoUS ⁴ consumption | 25,867 | 2,482 | 22,446 | 63,380 | 9,046 | 123,221 |
| Net Calif. with RoUS trade ⁶ | 7,091 | -141 | 1,437 | -6,007 | -700 | 1,680 |

Sources: US Bureau of the Census, USDA-NASS, USDA-ERS, UC-AIC and author calculations.

Notes: ¹ Includes vegetable oils, peanuts, sugar and sweeteners, coffee, tea, and spices

² Calculated as 12 percent of the U.S. consumption value of these items based on the California share of U.S. population.

³ RoW stands for rest of world.

⁴ RoUS stands for the rest of the United States.

⁵ Consumption is measured as U.S. production minus exports plus imports.

⁶ California production minus California consumption minus net California with RoW trade.

California Production and Use of Cotton, Animal Feeds and Ornamental Horticulture

California is a significant producer of cotton and, given its large population, a large user of cotton. U.S. consumption of cotton in the form of apparel and textile products totaled about 10.7 billion pounds in 2001. Raw cotton production in the United States totaled 9.7 billion pounds. Exports of raw cotton were about 5.3 billion pounds, while imports of raw cotton were not significant. The United States was a net importer of apparel and textile products, with net imports of 6.3 billion pounds. Based on California's population share of 12 percent of the national total, Californians consumed approximately 1.4 billion pounds of cotton in 2001. California production of cotton was approximately 0.99 billion pounds in 2001. Hence, California consumption of cotton exceeds production by approximately 0.4 billion pounds. California's net shipments from overseas and the rest of the United States are about 29 percent of consumption. (Sources for production and trade data of cotton and apparel and textile products were USDA Economic Research Service Reports on "Cotton and Wool Outlook.")

California uses substantial quantities of grain and protein supplements in the dairy, poultry and beef industries and produces relatively little of this animal feed. California is also a large producer and consumer of hay. The U.S. Customs Service tracks international exports and imports of feed grains, alfalfa, and other animal feeds, but no data are available for shipments within the United States. To approximate the use of animal feed in California, we approximated data on the number of marketable feed-consuming animal units in California. For animal feeds, we included soybeans, sunflowers (non-oil), all hay, corn (grain and silage), oats, rye, barley and sorghum. We did not include pasture feed and

attempted to exclude livestock fed on pasture. We included dairy and beef cattle, swine, poultry, sheep and horses. (We omitted beef bulls, beef cows and calves, and some sheep, which are primarily pasture based). Of the livestock we included, California feeds approximately 5.1 percent of the national herd. In dollar terms, the value of California feed production is approximately \$1.1 billion. The value of U.S. feed production is approximately \$46 billion. Taking into account U.S. international trade of animal feeds, the use of feed in the United States is about \$35 billion. California uses about \$1.8 billion worth of animal feed (\$35 billion times 5.1 percent). Hence, California produces about 61 percent by value of its use of animal feeds and imports about 39 percent (\$700 million), of its total animal feed from the rest of the United States and overseas. The share of 61 percent may be a slight overestimate because the value of U.S. feed trade used here already includes the value of California exports. However, there is no source of the value of exports at the farm gate.

(The sources for the data on California animal feeds are the CDFA 2002 Resource Directory, which provided 2001 data on the number of animals on California farms. The animal unit conversion factors are generally accepted and were obtained from USDA. The value of production for California and U.S. feed commodities was obtained from NASS/CASS. For U.S. trade, we used the United States International Trade Commission database, which uses export and import data as compiled by the U.S. Customs Service.)

In 2001, U.S. consumption of ornamental horticulture products was about \$8.5 billion, and California consumption was approximately \$1.1 billion based on its population share of approximately 12 percent. The value of production of ornamental horticulture in California was approximately \$3 billion. Exports to the rest of the world were only \$40 million, which leaves California as a net shipper of ornamental horticulture to the rest of the United States of about \$1.9 billion. (Value of production for California nursery/flower crops was derived from the CDFA 2002 Resource Directory. Production value data for the United States came from NASS reports on nursery crops and ornamental horticulture.)

Section 2. Projections to 2030

Projections for consumption were used to calculate the production such that California produces food sufficient for continued net export to the rest of the United States and foreign destinations (as discussed in AB 2587). These are discussed and followed by production projections.

Consumption Projections

Total food consumption in developed countries rises mainly with population growth. In the United States, the amount of consumer food value that is added off the farm has risen rapidly with income growth. Farm value of food consumption has also risen with income, but more slowly. Changes in the age and ethnic distribution of the population and changes in relative prices affect consumption patterns for specific food products. These are much less important for aggregate foods or large categories.

U.S. population is projected to grow by 24 percent, from 282 million to 351 million people, from 2000 to 2030 (U.S. Census Bureau). California population is projected to grow by 52 percent, from 34 million to 52 million people, during the same period (California Department of Finance). We use these figures as applicable to 2001 to 2030 and thus slightly overestimate demand growth relative to these sources. Real

per capita personal income is expected to grow slowly over this period, and California will become more Hispanic and more Asian.

Recent research from the USDA Economic Research Service projects per capita consumption to grow by about 10 percent for fruits, nuts and vegetables, grow by about 2 percent for grains, fall slightly for dairy, fall by about 3 percent for meats, and remain constant for the other category (Lin et al., 2003). The USDA study looked at consumption patterns for the year 2020. We extrapolated their projections to 2030.

Overall per capita food consumption rises about two percentage points over 30 years. The figures apply to California and to the United States as a whole. Combining population growth with per capita growth, we get the projections shown in Table 2 for overall food consumption and by category.

The percentage projections in table 2 are multiplied by the 2001 consumption numbers in table 1 to project consumption value for California agriculture in 2030. We compare these projections to projections of production to establish projection of net shipments out of California.

Table 2
Change in Food Consumption, 2001 to 2030

| | California | United States |
|----------------------------|--------------------------------|---------------|
| | <i>---Percentage growth---</i> | |
| Fruit, nuts and vegetables | 62 | 34 |
| Food grains | 54 | 26 |
| Dairy | 51 | 23 |
| Meats | 49 | 21 |
| Other | 52 | 24 |
| Total | 54 | 26 |

Projecting California Agricultural Production to 2030

Food production changes in California will derive primarily from the following six sources. Relative prices of food and the relative price across commodities affect all of these adjustments and are affected by them.

Agricultural Land

Agricultural land (or farmland) in California has been gradually shifting to urban or other nonagricultural uses. Recent analysis has shown that population growth and nonagricultural forces drive such development. About 500,000 acres were converted from agricultural to nonagricultural uses from 1990 to 2000 (Kuminoff, Sokolow and Sumner). We follow Kuminoff, Sokolow and Sumner and use standard U.S. government definitions of farmland that include pasture used for livestock grazing. Furthermore, we note that the U.S. government definitions also include a category of cropland used for grazing to reflect land that has and could be used for crops, but is at the time of a survey used for livestock grazing. Some irrigated cropland is also be used for pasture.

From 1990 to 2000, California population grew by 4.1 million and is projected to grow by about 17 million from 2001 to 2030, which is equivalent to about 5.7 million per decade. If farm to urban

conversion increases at the same rate for each additional Californian as it did in the 1990s, approximately 695,000 acres of California farmland will be converted to urban use per decade. At this rate, the total conversion of farmland from 2000 to 2030 will be about 2.1 million acres. According to the U.S. Census of Agriculture, between 1992 and 1997, the most recent data available, approximately 1.3 million acres were shifted out of farming and ranching in California, but about 0.8 million acres of cropland and 1.1 million acres of irrigated land were added.

If current patterns continue, the land converted will be a combination of irrigated cropland, nonirrigated cropland and pasture. Irrigated farmland acreage (irrigated cropland and irrigated pasture) in California in 2001 was about 9 million acres or approximately 31 percent of privately owned agricultural land in California. If irrigated cropland were shifted to nonfarm uses at the same rate as all cropland, then, under this scenario, approximately 690,000 acres of irrigated cropland in California would shift to nonfarm uses during the 30-year period. As in the past, the expanded use of multi-cropping of irrigated cropland is expected to offset some of the loss in irrigated acres. From 1994 to 2000, the increase in multi-cropping acreage almost offset the decrease in irrigated cropland acreage (Hawkins 2003). Even if only 50 percent of the loss in irrigated acreage is offset by multi-cropping, the net effect of the combination of shifting acreage and multiple use of cropland is a net loss of 345,000 acres from irrigated cropland use over the next 30 years.

Overall, we project that a maximum of 10 percent of California farmland, including both cropland and grazing land will be shifted out of agriculture by 2030.

Labor

Changes in farm labor availability depend on policy, demographic, economic growth outside of agriculture, and trends in Mexico. Labor use also depends on technical changes that increase productivity of labor. Such factors as immigration policy, education of farmers and farm workers, and the standard of living in Mexico also affect the cost and productivity of human capital on farms. Long-term trends suggest higher costs of hired farm labor, but higher productivity of all human capital in farming. We expect current trends to continue and that labor availability will not, limit production of California agriculture, though real labor costs will rise.

Regulations

Environmental, labor and other business regulations have continued to become more stringent over time. We expect this trend to continue. Regulations have affected land use in agriculture and productivity growth. In that sense, they are incorporated in the resource use and yield growth estimates. Government agricultural policy also affects farm production by affecting the relative income from alternative crops through subsidy. Most California commodities receive little subsidy or protection. Feed grains, wheat, rice, cotton, sugar and dairy are major exceptions. Producer support estimates (PSEs) as a share of production value for important California commodities show that certain commodities receive substantial support, while others receive close to nothing. Estimates by Sumner and Brunke (2003) show that the average PSE is approximately 11 percent across all California commodities. Producer support has recently been very high for rice at over 70 percent and sugar beets at over 65 percent. Cotton and wheat PSEs are also far above the average. Dairy, the state's most important agricultural sector in terms of market value, has a PSE of more than 30 percent. Fruits and nuts, vegetables and melons, and flower and nursery products have PSEs in the low single-digit range. Current trends are for the production effects of subsidies to decline over time and for trade protection from imports to be reduced. Continuation of these

trends would be required for the United States itself to comply with U.S. proposals in international trade negotiations. With reduced production enhancing incentives of farm subsidies, land will shift from rice, sugar beets, wheat, feed grains and cotton to less subsidized crops. The result will be more food value produced in California. The trend for dairy is mixed because relaxation of the dairy subsidy will shift U.S. dairy production toward California, and with trade agreements, the world prices for dairy products will rise. We expect little change in California dairy production if subsidies are relaxed. Changes in farm subsidy may also facilitate acreage shifts.

Acreage Shifts Across Crops

Acreage shifts across crops in California have accounted for substantial gains in the value of food production. For example, barley acreage has declined over the past 30 years and cotton acreage has declined over the past 20 years (after an increase in the 1970s). Acres of grapes, almonds and other horticultural crops have increased. Significant potential remains for continued acreage shifts. We would expect these shifts to continue, as demand growth and California's comparative advantage will continue to favor expansion of fruits, nuts and vegetables over the next 30 years. The total acreage of vegetables, fruit and nuts in California was about 3.9 million acres in 2002. Acreage for cotton, alfalfa and irrigated pasture was about 2.8 million acres in 2002. As the demand for California vegetables, fruit and tree nuts grows, cotton, alfalfa and irrigated pasture acreage in the state is likely to shift toward these crops. Furthermore, California has 20 million acres of non-irrigated pastureland and non-irrigated cropland and 6.9 million acres of pastureland in the Central Valley (Kuminoff, Sokolow and Sumner, 2001). As relative prices and policy adjustments continue to favor the shift of resources, there will be a gradual increase in the value of food production in California. A 10 percent increase in the value of food production from acreage shifts is a conservative estimate.

Climate Change and Environmental Resources

Yield growth per acre of land has been a key factor in expanding California agricultural production. Consider first projected effects of climate change over the next three decades. The best estimates available for California crops indicate that climate change over the next three decades will increase yields by an average of 15 percent for major California crops (Adams, Wu and Houston, 2003). Additional references on climate change can be found in Mendelsohn, Nordhaus and Shaw, Adams et al. and Segerson and Dixon.

The average we use is smaller than the increases in yields expected as a consequence of climate change for such important California food commodities as grapes, tomatoes and almonds. Wine grape yields, for example, are expected to increase due to projected climate change by 34 percent by 2030. The projected yield increase due to climate change is 40 percent for almonds. (Appendix C provides more information on the projected effects of climate change on crop yields per acre for food crops in California.) Other resource changes are air quality and soil quality. Despite some crop and location specific adjustments, we see no trends that suggest major reductions in productivity from changes in these resources. We do not discuss water availability here in this context.

Crop Yields and Technical Change

Growth in the quantity of food crop production per acre of land will continue to be an important driving force in increasing the value of California food crop production over the next three decades, as it has been in previous decades.

We base our analysis of crop yields on historical yield growth data from 1960–2002. Using these data, we created a yield index for each of 30 California food crops. We then aggregated these indices into an overall California crop yield index using the value share over the period 1997–2001. Using these data, we calculated that the mean percentage rate of growth in the aggregate food-crop yield index over the period 1960–2002 was 1.42 percent per year. This number simply says that over a 42-year period of year-to-year yield changes, the simple average of percentage changes was 1.42 percent per year.

Alternatively, we examined several trend lines fit to the aggregate food-crop yield index and to yield indices for individual crops. The log-linear trend line for the aggregate food-crop yield index has a slope coefficient of 1.11 percent. Table 3 lists the log-linear trends for individual commodities or commodity groups for 1960–2002, which differ considerably across crops. These log-linear trends are also measures of percentage changes over the period.

In table 3, vineyard crops are the most important commodity group in the overall index. The relatively low yield growth can be explained by trends in the industry to lower producing, higher quality varieties and to technologies that limit yield while improving quality. The growth rate for vineyards, therefore, does not seem to represent slow technical improvement.

In our projections to 2030, we used an average yield growth for California food crops of 1.20 percent per year, which we think is conservative. Compounded over 30 years, the total growth rate is 43 percent. Such growth relies on technological advances and the application of such advances in California. It also relies on managerial improvement and innovation on the part of growers. One part of this equation that raises concern is the potential for a failure to invest in agricultural science in California. However, given the long time lags from scientific innovation to productivity growth, we are confident in our conservative productivity growth estimate being met or exceeded.

Table 4 summarizes the base production projections

The growth in California food consumption and shipments to the rest of the United States can now be projected using the base data in table 1 and the consumption and production projections to 2030. Appendix B contains a sensitivity analysis of certain parameters used here.

Table 5 uses the data and projections from tables 1, 2 and 4 to compare food production and consumption for the year 2030. As in previous tables, we aggregate across individual food products using value terms. Column A in table 5 presents the “use” of 2001 California production of food commodities. California food consumption equaled 82.2 percent of California food production in 2001. Shipments to the rest of the United States accounted for 8.2 percent of California production. Net exports to international markets equaled 9.6 percent of 2001 California production (Table 5a). These three shares are obtained from the production and consumption figures presented in table 1. Column B in table 5 contains the proportional change in consumption due to demand growth following population increase. The figures for California consumption and consumption in the rest of the United States are obtained from table 2. Column C of table 5 shows that California food production must grow by 46.5 percent from 2001 to 2030 (44.4 percent for California and 2.1 percent for the rest of the United States) in order to hold both the ratio of California food consumption to California food production and the ratio of rest-of-the-U.S. food consumption to California food production constant at the 2001 values.

However, the total projected growth in California food production value by 2030 equals 58 percent (table 4). The difference between this growth in production and the growth in demand in California and the rest of the United States is 11.5 percent, which is the share in the growth of California food production that will be available for international exports in 2030. This implies that international exports by the year 2030 will grow by 20 percent compared to 2001 (11.5 percent divided by 9.6 percent, table 5a). A further underlying assumption in this analysis is that market forces are allowed to operate in both input and output markets for California agriculture. In particular, if market prices for farm output fall faster than costs fall in real terms, given productivity growth in California, land prices may decline, but land will remain in production. We do not expect significant amounts of land suited for food crops in California to be removed from production over the next 30 years except that portion that is converted to urban uses. Appendix B looks at these findings in more detail and provides estimates for alternative growth rates in production.

Table 6 summarizes the projected growth in inflation adjusted value terms and shows the production and distribution of California food in 2030 compared to 2001.

Conclusions

Tables 4 to 6 summarize the projections and net effects of several changes in California food supply and demand over the next 30 years. The projections shown here rely on some tentative data and assumptions and may change as more data and fuller analysis become available. However, it is unlikely that the dominant driving forces for both production and consumption discussed above will change significantly. As a result, the major findings shown in tables 4 to 6 are unlikely to change substantially. The main conclusion that can be drawn from tables 4 to 6 is that California agriculture will continue to produce substantial quantities of food crops. Furthermore, crop shifts and the productivity growth of California agriculture suggest that the value of California food production will more than keep up with rising population and income growth in California and the rest of the United States. A 10 percent net loss of farmland and irrigation water resources will be more than offset by shifts toward crops with high value per acre, growth in production per acre due to technological improvement, and yield growth attributable to climate change. These productivity growth factors will likely enable California agricultural production to expand such that the inflation-adjusted farm gate value of net food exports to the rest of the world will expand, not contract.

Table 3
Log-Linear Trend Growth Rates for Yield Per Acre for Major California Food Crops and Crop Groups, 1960-2002

| Wheat | 1.80 |
|----------------------------|-------------|
| Rice | 1.35 |
| Proc. Tomatoes | 1.75 |
| Fresh Tomatoes | 1.20 |
| Cucurbits | 1.17 |
| Other Vegetables | 1.01 |
| Almonds/Pistachios | 2.33 |
| Other Deciduous tree crops | 0.82 |
| Subtropical crops | 0.72 |
| Vineyard crops | 0.90 |

Table 4
Changes in California Food Production 2001–2030, in Value Terms

| Source | Percent change |
|--|-----------------------|
| Technical change (1.2% per year) | + 43 |
| Climate change yields growth, yield/acre | + 15 |
| Crop shifts | + 10 |
| Land loss to urbanization and other | - 10 |
| Net production change | + 58 |

Table 5
Projected Growth in California Food Consumption and Exports 2001–2030, in Value Terms

| | Year 2001 % of California Production¹ | Proportional Growth from 2001 to 2030² | Growth in California Food Supplies to Satisfy Demand |
|------------------------|---|--|---|
| | (A) | (B) | C=(A*B) |
| California Consumption | 82.2% | 0.54 | 44.4% |
| Rest of US Consumption | 8.2% | 0.26 | 2.1% |
| Sum | | | 46.5% |

¹ Based on table 1, last column.

² Based on table 2, bottom row.

Table 5a
Derived Growth in California International Exports

| | Year 2001 % of California production¹ | Derived proportional growth from 2001 to 2030 | Growth in California food supplies available for international exports |
|-----------------|---|--|---|
| | (A) | B=(C/A) | (C) |
| RoW net exports | 9.6% | 1.20 | 11.5% ² |

¹ Based on table 1, last column.

² Difference of net production change (table 4, bottom row) and growth in California food supplies to satisfy increase in California and U.S. demand (58%, table 4, bottom row).

Table 6
Absolute Projected Growth in California Food Production, Consumption
and Exports, 2001-2030, in Value Terms, in Million Dollars (in 2001 Dollars)

| | 2001 | Growth factor | 2030 |
|-------------------------|-------------|----------------------|--------------------|
| California production | 20,446 | 0.58 | 32,305 |
| California consumption | 16,802 | 0.54 | 25,875 |
| Net RoUS exports | 1,680 | 0.26 | 2,177 |
| Derived RoW net exports | 1,964 | 1.20 ¹ | 4,313 ¹ |

¹ Derived as a residual.

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Appendix A. Value Per Unit of Irrigation Water

Irrigation efficiency has been improving for decades with better technologies available and more adoption of these technologies. For example, more use of drip and sprinkler irrigation has led to less incidental evaporation per unit of applied water. In addition, in California there has been a shift to commodities that produce more crop value per unit of water. From 1972 to 1995, total acre-feet of irrigation water use in California has increased only slightly. The gross value of production per acre has increased substantially. Gross value of production per acre-foot has increased even more (Table A.1). In 1972, California agriculture generated \$185 nominal terms per acre-foot of irrigation water applied (\$576 in 1996 dollars using the GDP deflator (Implicit Gross Domestic Product Price Deflator)) or \$375 in 1996 dollars using the index of prices received by farmers. In 1995, nominal value per acre was \$672 per acre-foot in nominal terms, (\$687 per acre-foot in 1996 dollars using the GDP deflator and \$721 in 1996 dollars using the index of prices paid by farmers). The growth in value per acre-foot of water was 264 percent over these 23 years using the nominal values, 19.3 percent using values deflated by the GDP deflator and 92.6 percent using values deflated by the prices received by farmers index.

Table A.1
Changes in Dollar Value of Production Per Acre Foot of Applied Water

| Year | Dollar value of production per acre foot of irrigation water (applied water) | | |
|----------------|--|--------------------------|--|
| | Nominal | Deflated by GDP deflator | Deflated by prices received by farmers |
| 1972 | 185 | 576 | 375 |
| 1995 | 673 | 687 | 721 |
| Percent change | 264 | 19.3 | 92.6 |

Source: California DWR, U.S. Bureau of Economic Analysis (GDP deflator used with 1996=100), USDA-ERS.

Appendix B. Sensitivity Analysis

The most important factors affecting production growth are growth in yield per acre attributable to technical change and growth in yield per acre attributable to climate change. In order to provide information on the robustness of these factors, sensitivity of the results to changes in these factors is presented in this appendix.

According to table 4 in the main text, California would need to supply 44.4 percent more food by the year 2030 to meet its current ratio of California food consumption to California food production. Another 2.1 percent increase by 2030 would be necessary to maintain the current ratio of rest-of-the-U.S. food consumption to California food production. The additional food supply from the main sources totaled 58 percent, which would be more than enough to meet 2030 net food requirements in California and California's share to the rest of the United States under our baseline scenario.

We now look at a range of the parameters that contribute to the change in California's food production by 2030. Two essential parameters are the impact of technical change and the impact of climate change on future food supply. Our baseline scenario, which is based on an econometric analysis of yield data from 1960–2002, uses an annual growth rate in output/acre of 1.2 percent attributable to technical change. We also attribute 15 percent yield growth over 30 years to climate change. This appendix investigates alternative annual growth rates attributable to technical change and to climate change.

Table B.1 presents the results for three alternative rates of growth attributable to technical change and three alternative growth rates attributable to climate change. Assuming a high technical growth rate of 1.4 percent per year, together with the other base assumptions, the total growth in production over 30 years equals 66 percent. This scenario leaves room for a large expansion in international food exports from California. Assuming a lower annual growth rate attributable to technical change of 1 percent, the resulting overall growth in California food production totals 49 percent from 2001 to 2030. Population growth in California and the United States require California food production to increase by 46.5 percent to keep the net contribution to food supply constant. This leaves a surplus of 2.5 percent, which can be used for California international net exports of food commodities. The next row shows the minimum growth in technical change necessary to meet the increased demand for food in California and to the rest of the United States in the year 2030. In order to meet that criterion, output per acre would need to grow by 31.5 percent over 30 years, which is equivalent to an annual growth rate of 0.9 percent.

In the lower half of table B.1, we apply the same kind of sensitivity analysis to three scenarios about the effects of climate change on production of food in California. Our baseline scenario uses a 15 percent growth in the value of food production as the consequence of climatic change over the period 2001-2030. Table B.1 shows the impacts on California food production in 2030 and net food balances, if the impact of climatic change is 20 percent or 10 percent. With a 20 percent growth in yields attributable to climate change the total production increase is 63 percent from 2001 to 2030, and international food exports increase substantially. If instead climate change causes only a 10 percent yield increase, the net international exports decline compared to the base scenario.

With the same base values for other parameters, a yield growth due to climate change of only 3.5 percent implies that growth in productivity equals growth in demand in the United States and in the rest of the United States. Table B.1.b is presented in the same format at table 5.a in the text. Table B.1.b presents the derived growth in food supplies available for international exports under the different assumptions of growth attributable to technical change and attributable to climate change (column C). We then derive the proportional growth factors under these different scenarios (column B).

Table B.1
Analysis of Various Growth Rates Attributable to Technical Change (Output Per Acre)
and Attributable to Climate Change and Their Impact on the Value of Total Additional
Output in 2030 and the Derived Growth in California International Exports

| | Output/acre growth, by 2030¹ | Climate change² | Crop shift | Land loss | Net change | Domestic demand growth³ | Internatl. net exports⁴ |
|---|--|---------------------------------------|-----------------------|----------------------|-----------------------|---|---|
| Base case ⁵ | +43% | +15% | +10% | -10% | +58% | +46.5% | +11.5% |
| Output/acre growth, 1.4%/year | +51% | +15% | +10% | -10% | +66% | +46.5% | +19.5% |
| Output/acre growth, 1.0%/year | +34% | +15% | +10% | -10% | +49% | +46.5% | +2.5% |
| Output/acre growth, 0.9%/year ⁶ | +31.5 | +15% | +10% | -10% | +46.5% | +46.5% | 0% |
| Climate change growth, high | +43% | +20% | +10% | -10% | +63% | +46.5% | +16.5% |
| Climate change growth, low | +43% | +10% | +10% | -10% | +53% | +46.5% | +6.5% |
| Climate change growth, min 3.5% ⁶ | +43% | +3.5% | +10% | -10% | +46.5% | +46.5% | 0% |

¹ The column presents the compounded growth in output per acre assuming various growth rates. ² The column presents the various growth rates attributed to climate change.

³ Domestic demand growth includes the additional demand from growth in California population and population in the rest of the United States (based on Table 5).

⁴ This column contains the share of food produced in California that can be used for international exports under the various growth rates in output/acre.

⁵ Base case reported in tables 4, 5 and 5a.

⁶ The minimum growth rate attributable to output/acre (row 4) and attributable to climate change (bottom row) to equal the demand growth in California and the rest of the United States (but not leave any food products for international exports).

Table B.1b
Derived Growth in Value of California International Exports

| | Year 2001 % of California production ¹ | Derived proportional growth from 2001 to 2030 | Growth in California food supplies available for international exports ² |
|----------------------------|---|---|---|
| | (A) | $B=(C/A)$ | (C) |
| Base case | 9.6% | 1.20 | 11.5% |
| High output/acre growth | 9.6% | 2.03 | 19.5% |
| Low output/acre growth | 9.6% | 0.26 | 2.5% |
| High climate change growth | 9.6% | 1.72 | 16.5% |
| Low climate change growth | 9.6% | 0.68 | 6.5% |

¹ Based on table 1, last column.

² Based on table B.1.

Appendix C. Climate Change

Adams, Wu and Houston (2003) provide estimates on projected yield growth as a consequence of global climate change in a study prepared for the Electric Power Research Institute and the California Energy Commission. One step in their research was to develop crop yield response functions that estimate the effects of changes in temperature and precipitation on yields of major crops in California. They then apply these to climate change scenarios. The resulting yield estimates are presented for a range of climatic change scenarios and include assumptions concerning the effects of changes in CO₂ levels on crop yields. The information obtained for the three time periods modeled in the study are presented in tables C.1 through C.4 for the four production regions identified in the study:

Sacramento and the Delta regions, including Butte, Colusa, Contra Costa, Glenn, Sacramento, San Joaquin, Solano, Sutter, Tehama, Yolo and Yuba counties

San Joaquin and Desert Regions, including Fresno, Imperial, Kern, Kings, Madera, Merced, Riverside, Stanislaus and Tulare counties

North East and Mountain Regions: Calaveras, El Dorado, Lassen, Mariposa, Modoc, Nevada, Placer, Shasta, Siskiyou and Tuolumne counties.

Coast Regions, including Lake, Los Angeles, Monterey, Napa, Orange, San Benito, San Diego, San Luis Obispo, Santa Barbara and Sonoma counties

These estimates provide the basis for our projections of the impacts of climate change on yields by 2030.

Table C.1
Percent Change in Yields for the Sacramento and Delta Regions
of California, by Uniform Scenario, with CO₂ Fertilizer Effects

| Year forecasted | 2100 | 2100 | 2100 | 2060 | 2020 | 2020 | 2020 | 2020 |
|--------------------------|----------------------------|--------|--------|-------|-------|-------|--------|-------|
| Temperature change (C°) | 3.00 | 3.00 | 5.00 | 1.80 | 0.60 | 1.50 | 5.00 | 1.50 |
| Temperature change (F°) | 5.40 | 5.40 | 9.00 | 3.24 | 1.08 | 2.70 | 9.00 | 2.70 |
| Precipitation change % | 0% | 18% | 0% | 11% | 4% | 9% | 30% | 0% |
| Crop | Change in yield (% change) | | | | | | | |
| Corn grain | 14.6% | 17.5% | 27.5% | 10.5% | 5.1% | 9.0% | 33.0% | 7.7% |
| Corn silage | 2.8% | 4.6% | 0.4% | 4.2% | 3.5% | 4.0% | 4.7% | 3.4% |
| Barley | 4.8% | 2.8% | -4.3% | 8.5% | 13.6% | 9.9% | -7.9% | 10.7% |
| Sorghum | 3.9% | 3.0% | 0.1% | 4.7% | 5.7% | 5.0% | -1.5% | 5.5% |
| Dry beans | 23.3% | 47.1% | 26.3% | 32.3% | 22.9% | 29.1% | 84.8% | 21.4% |
| Oats | 15.4% | 13.8% | 12.4% | 15.0% | 15.7% | 15.2% | 11.1% | 16.2% |
| Rice | 21.9% | 20.9% | 24.9% | 19.0% | 16.5% | 18.4% | 22.9% | 18.8% |
| Sugar beets | 28.1% | 30.9% | 36.7% | 25.6% | 21.6% | 24.5% | 42.5% | 23.4% |
| Winter wheat | 16.9% | 13.2% | 20.2% | 13.7% | 14.9% | 14.0% | 14.2% | 15.8% |
| Orange, Valencia | 37.9% | 30.0% | 39.8% | 33.8% | 33.6% | 34.2% | 14.2% | 35.4% |
| Hay, alfalfa | 20.1% | 20.6% | 26.4% | 16.3% | 12.1% | 15.2% | 28.1% | 15.1% |
| Grapes, table and raisin | 7.5% | -10.0% | -16.7% | 8.5% | 20.8% | 12.4% | -54.9% | 19.1% |
| Grapes, wine | 37.9% | 35.6% | 44.1% | 31.8% | 27.4% | 30.8% | 40.3% | 32.0% |
| Tomatoes, fresh | 15.7% | 16.7% | -3.6% | 22.4% | 24.9% | 23.3% | 0.2% | 23.3% |
| Tomatoes, process | 29.4% | 25.5% | 32.2% | 25.8% | 25.5% | 25.9% | 23.0% | 27.2% |
| Almonds | 78.8% | 79.8% | 121.6% | 56.2% | 35.8% | 50.8% | 126.3% | 51.0% |
| Walnuts, English | 32.5% | 26.8% | 35.1% | 26.8% | 25.8% | 26.7% | 24.5% | 29.3% |
| Prunes, dried | 63.4% | 65.9% | 100.5% | 46.7% | 31.3% | 42.5% | 106.5% | 41.6% |
| Olives | 3.9% | 3.2% | -22.8% | 14.4% | 22.2% | 16.7% | -22.8% | 17.3% |
| Potatoes | -5.2% | -5.8% | -14.1% | -0.8% | 3.8% | 0.4% | -15.1% | 0.7% |

This region includes Butte, Colusa, Contra Costa, Glenn, Sacramento, San Joaquin, Solano, Sutter, Tehama, Yolo and Yuba counties.
Source: Adams, Wu and Houston.

Table C.2
Percent Change in Yields for the S.J. Valley and Desert Regions of
California, by Uniform Scenario, with CO₂ Fertilizer Effects

| Year forecasted | 2100 | 2100 | 2100 | 2060 | 2020 | 2020 | 2020 | 2020 |
|--------------------------|----------------------------|--------|--------|-------|-------|-------|--------|-------|
| Temperature change (C°) | 3.00 | 3.00 | 5.00 | 1.80 | 0.60 | 1.50s | 5.00 | 1.50 |
| Temperature change (F°) | 5.40 | 5.40 | 9.00 | 3.24 | 1.08 | 2.70 | 9.00 | 2.70 |
| Precipitation change % | 0% | 18% | 0% | 11% | 4% | 9% | 30% | 0% |
| Crop | Change in yield (% change) | | | | | | | |
| Corn grain | -3.3% | -4.1% | -13.5% | 0.2% | 2.8% | 1.0% | -15.1% | 1.3% |
| Corn silage | 6.3% | 7.9% | 7.1% | 6.2% | 4.2% | 5.7% | 10.0% | 5.0% |
| Barley | 2.1% | -2.2% | -9.8% | 5.7% | 12.4% | 7.6% | -18.3% | 9.4% |
| Sorghum | 1.7% | 1.1% | -0.7% | 2.8% | 4.6% | 3.2% | -1.7% | 3.5% |
| Cotton, pima | 9.9% | 7.7% | -1.1% | 12.0% | 12.4% | 12.5% | -8.5% | 12.8% |
| Cotton | 5.3% | 2.9% | -7.6% | 8.4% | 11.3% | 9.4% | -11.8% | 10.5% |
| Drybeans | 10.9% | 6.4% | 4.4% | 12.5% | 17.3% | 13.9% | -6.7% | 15.3% |
| Oats | -17.5% | -17.1% | -63.4% | 0.8% | 11.7% | 4.1% | -62.0% | 4.1% |
| Rice | 7.4% | 5.0% | -2.6% | 10.7% | 15.0% | 12.0% | -8.1% | 12.9% |
| Sugarbeets | 12.5% | 14.2% | 9.0% | 15.4% | 16.9% | 15.7% | 13.1% | 15.1% |
| Winter wheat | 12.7% | 9.7% | 5.9% | 12.7% | 14.2% | 13.3% | 0.9% | 14.9% |
| Durum wheat | 18.9% | 20.7% | 18.9% | 18.6% | 15.5% | 17.9% | 22.1% | 17.0% |
| Orange, Valencia | 17.5% | 7.3% | 16.7% | 13.6% | 16.0% | 14.7% | -12.9% | 17.0% |
| Hay Alfalfa | 18.7% | 19.3% | 24.3% | 15.4% | 11.6% | 14.4% | 26.0% | 14.3% |
| Grapes, table and raisin | -13.2% | -27.5% | -50.4% | -2.5% | 16.5% | 3.0% | -83.1% | 8.2% |
| Grapes, wine | 41.5% | 40.2% | 46.3% | 37.0% | 33.1% | 36.1% | 44.3% | 36.7% |
| Tomatoes, fresh | -12.4% | -10.7% | -46.6% | 3.3% | 13.9% | 6.2% | -41.4% | 5.9% |
| Tomatoes, process | 27.1% | 24.0% | 29.5% | 24.3% | 23.9% | 24.3% | 21.7% | 25.3% |
| Almonds | 78.8% | 79.8% | 121.6% | 56.2% | 35.8% | 50.8% | 126.3% | 51.0% |
| Walnuts, English | 32.6% | 29.1% | 33.5% | 29.3% | 28.6% | 29.3% | 26.5% | 30.8% |
| Prunes, dried | 68.4% | 70.1% | 104.7% | 50.7% | 34.1% | 46.3% | 108.8% | 45.7% |
| Olives | -15.0% | -14.9% | -55.9% | 4.1% | 19.5% | 8.3% | -54.5% | 8.6% |
| Avocados | 26.0% | 8.9% | 25.2% | 18.4% | 23.5% | 20.3% | -17.8% | 25.6% |
| Potatoes | -8.9% | -9.3% | -19.4% | -3.4% | 2.1% | -1.9% | -20.1% | -1.8% |

This region includes Fresno, Imperial, Kern, Kings, Madera, Merced, Riverside, Stanislaus and Tulare counties.

Source: Adams, Wu and Houston.

Table C.3
Percent Change in Yields for the North-East and Mountain Regions
of California, by Uniform Scenario, with CO₂ Fertilizer Effects

| Year forecasted | 2100 | 2100 | 2100 | 2060 | 2020 | 2020 | 2020 | 2020 |
|-------------------------|----------------------------|-------|--------|--------|--------|--------|--------|--------|
| Temperature change (C°) | 3.00 | 3.00 | 5.00 | 1.80 | 0.60 | 1.50 | 5.00 | 1.50 |
| Temperature change (F°) | 5.40 | 5.40 | 9.00 | 3.24 | 1.08 | 2.70 | 9.00 | 2.70 |
| Precipitation change % | 0% | 18% | 0% | 11% | 4% | 9% | 30% | 0% |
| Crop | Change in Yield (% change) | | | | | | | |
| Corn grain | -3.3% | -0.3% | -16.4% | 2.2% | 2.0% | 2.4% | -10.4% | 1.1% |
| Corn silage | 9.2% | 9.2% | 13.3% | 6.7% | 4.3% | 6.1% | 13.3% | 6.1% |
| Barley | 33.4% | 30.9% | 58.1% | 22.1% | 17.1% | 20.5% | 54.0% | 21.8% |
| Oats | 8.6% | 7.9% | 12.1% | 7.5% | 8.0% | 7.5% | 10.7% | 7.8% |
| Rice | -0.7% | -3.7% | 15.8% | -10.7% | -16.5% | -12.2% | 10.7% | -10.8% |
| Sugarbeets | 19.7% | 26.0% | 19.8% | 23.5% | 21.3% | 22.9% | 30.7% | 19.7% |
| Winter wheat | 3.3% | 3.6% | -0.2% | 6.0% | 8.6% | 6.6% | 0.4% | 6.4% |
| Hay, alfalfa | 24.4% | 24.8% | 33.8% | 18.7% | 12.6% | 17.1% | 35.4% | 17.1% |
| Grapes, wine | 86.8% | 80.7% | 107.4% | 69.4% | 57.1% | 66.5% | 97.3% | 69.6% |
| Walnuts, English | 68.1% | 52.0% | 83.3% | 48.1% | 42.5% | 47.0% | 54.6% | 54.7% |
| Olives | 23.0% | 23.0% | 9.9% | 26.7% | 27.8% | 27.3% | 10.8% | 27.5% |
| Potatoes | -4.7% | -5.3% | -11.0% | -1.8% | 1.5% | -0.9% | -12.0% | -0.6% |

This region includes Calaveras, El Dorado, Lassen, Mariposa, Modoc, Nevada, Placer, Shasta, Siskiyou and Tuolumne counties.

Source: Adams, Wu and Houston.

Table C.4
Percent Change in Yields for the Coast Region of California,
by Uniform Scenario, with CO₂ Fertilizer Effects

| Year forecasted | 2100 | 2100 | 2100 | 2060 | 2020 | 2020 | 2020 | 2020 |
|-------------------------|----------------------------|--------|--------|--------|--------|--------|--------|--------|
| Temperature change (C°) | 3.00 | 3.00 | 5.00 | 1.80 | 0.60 | 1.50 | 5.00 | 1.50 |
| Temperature change (F°) | 5.40 | 5.40 | 9.00 | 3.24 | 1.08 | 2.70 | 9.00 | 2.70 |
| Precipitation change % | 0% | 18% | 0% | 11% | 4% | 9% | 30% | 0% |
| Crop | Change in Yield (% change) | | | | | | | |
| Corn grain | 42.1% | 35.0% | 57.0% | 31.1% | 25.6% | 30.0% | 37.3% | 31.7% |
| Corn silage | -31.3% | -34.6% | -45.5% | -27.8% | -24.4% | -26.6% | -53.7% | -25.5% |
| Barley | 15.1% | 15.4% | 18.7% | 14.5% | 14.7% | 14.4% | 19.6% | 14.4% |
| Drybeans | 34.7% | -3.3% | 49.1% | 11.1% | 20.7% | 14.5% | -39.9% | 27.7% |
| Oats | 37.8% | 33.1% | 43.6% | 34.6% | 36.8% | 35.1% | 32.4% | 36.7% |
| Sugarbeets | 48.5% | 66.6% | 76.8% | 46.3% | 28.5% | 41.3% | 106.5% | 32.1% |
| Winter wheat | -1.6% | 2.0% | 9.3% | -2.1% | -3.7% | -2.8% | 14.6% | -4.7% |
| Orange, Valencia | 13.1% | 10.5% | 4.5% | 17.6% | 22.8% | 19.1% | -5.8% | 19.1% |
| Hay, alfalfa | 26.2% | 27.0% | 30.8% | 23.7% | 20.4% | 22.9% | 32.9% | 22.6% |
| Grapes, wine | 90.2% | 84.4% | 85.0% | 87.7% | 89.5% | 88.4% | 75.4% | 91.4% |
| Tomatoes, fresh | 32.7% | 34.1% | 31.1% | 30.2% | 23.9% | 28.9% | 35.0% | 28.5% |
| Tomatoes-process | 21.5% | 17.6% | 24.8% | 17.8% | 17.1% | 17.7% | 15.5% | 19.0% |
| Almonds | 78.8% | 79.8% | 121.6% | 56.2% | 35.8% | 50.8% | 126.3% | 51.0% |
| Walnuts, English | 79.9% | 68.9% | 75.8% | 74.3% | 77.7% | 75.5% | 55.3% | 80.5% |
| Prunes, dried | 83.3% | 86.5% | 113.5% | 72.0% | 62.0% | 69.0% | 121.1% | 67.9% |
| Avocados | 29.0% | 13.4% | 30.7% | 20.8% | 23.9% | 22.2% | -9.3% | 26.9% |
| Potatoes | -16.1% | -16.7% | -22.9% | -12.8% | -9.2% | -11.8% | -24.1% | -11.5% |

This region includes Lake, Los Angeles, Monterey, Napa, Orange, San Benito, San Diego, San Luis Obispo, Santa Barbara and Sonoma counties.

Source: Adams, Wu and Houston.

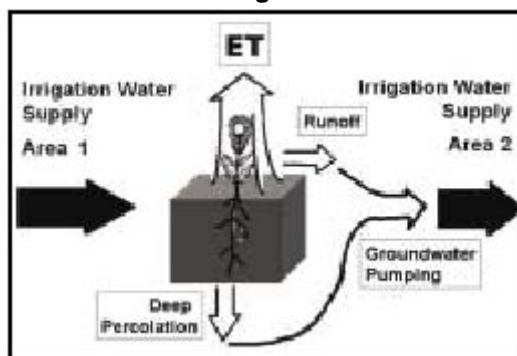
The Promise of Regulated Deficit Irrigation in California's Orchards and Vineyards

By David A. Goldhamer, Water Management Specialist, University of California, and Elias Fereres, Professor, IAS-CSIC and University of Cordoba, Spain

Agriculture uses about 75 percent of all the developed water in California, and the expanding population and efforts to maintain or improve animal habitat and stream flows will require even more water in the future. With no significant expansion of water supplies and possible partial loss of existing resources, agricultural water use is being seen by many as a potential water source. The recent controversy over the transfer of water from agriculture in Imperial County to the City of San Diego illustrates this issue. Some maintain that Imperial growers could free up the amount of water in question by improving their surface irrigation management, such as waste less water by reducing deep percolation below the crop root zone or end of field runoff. The growers argue that there are limits to how much water can be saved by reducing irrigation water losses (also called improving application efficiency) and point to reduced planting acreage, increased salinity, and associated loss of production and agricultural jobs as likely effects.

Statewide, California growers have steadily improved their application efficiency over the last couple decades. Moreover, deep percolation and runoff are usually only temporary losses on a small scale (the field being irrigated). Although quality may be degraded by fertilizers and other agricultural chemicals, water lost to deep percolation eventually moves into the water tables where it can be pumped and reused (see Figure 1). An exception to this is when it enters a salty, perched water table, usually making it unusable, or when it flows to the ocean. Runoff is often collected and reused on another field on the farm. Recognizing this and the fact that most California growers have become highly efficient in their irrigation management shows that there is limited opportunity to free up net water by improving application efficiency. Additionally, the use of California Irrigation Management Information System (see “Quantitative Irrigation Scheduling Does Work”) data has allowed growers not to over-irrigate crops, minimizing the loss of water to deep percolation.

Figure 1
Fate of Irrigation Water



Generally a near-linear relationship exists between ET and crop production because transpiration, the movement of water vapor from the interior of the leaf to the surrounding atmosphere and the uptake of carbon dioxide, the basic building block required in the process of photosynthesis, both use the same plumbing at the leaf surface—the stomata. These are very small openings usually located on the undersides of leaves that regulate the movement of both water vapor and carbon dioxide. Indeed, it's often said that the plant trades water for carbon and if the goal is to maximize carbon uptake to achieve high yields, potential transpiration must be met. Thus, limiting transpiration (water stress) has usually been associated with production losses and lower grower profit.

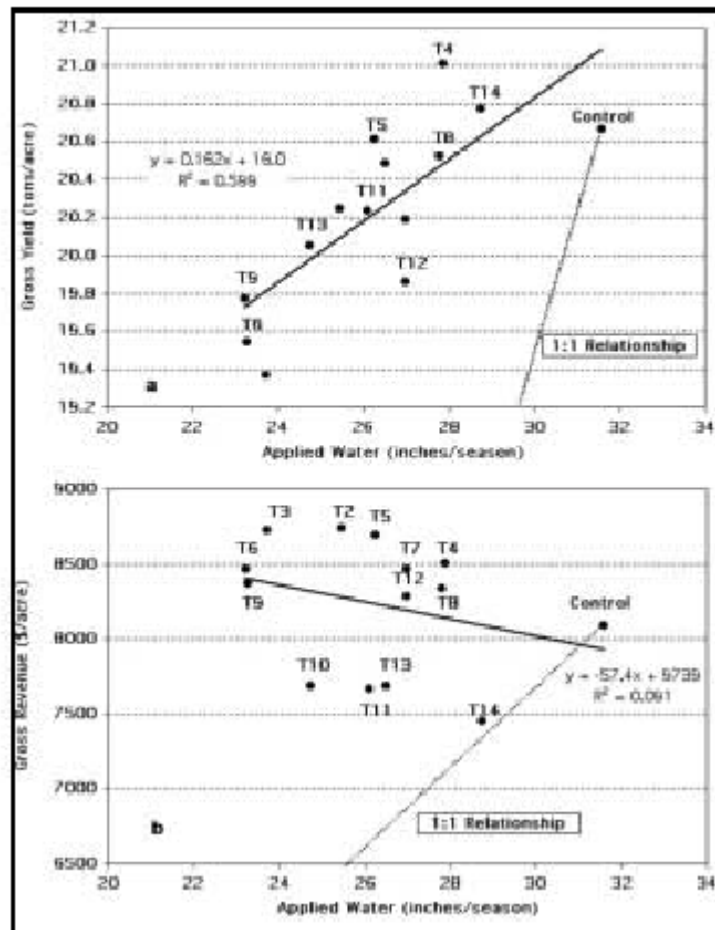
While this is true for most field and row crops, it's not necessarily true for trees and vines. Lack of water (water stress) reduces the vegetative growth of plants but doesn't necessarily result in reduced fruit yield in trees and vines as it does with most field and row crops (cotton being an exception). Thus it is possible to reduce transpiration of trees and vines without reducing yield.

We have conducted RDI research on the major tree crops in California—pistachio, olive, prune, and citrus—and identified numerous species where significant amounts of water can be saved without having a negative impact on production or grower profit. We found that while the relationship between gross fruit yield (mean of three years) and applied water was fairly linear (see Figure 2a) relationship between gross revenue (\$/acre) and applied water was completely different (see Figure 2b). Many of the RDI regimes had higher gross revenue than the full irrigation control while applying from 4 to 8 inches less water. This was due to significantly lower creasing (higher fruit quality), especially with early season stress. This illustrates a major difference between row/field crops and tree/vine crops.

Almond trees present the best opportunity to couple RDI with adjusted horticultural management not only to reduce water consumption but also to address two critical health issues facing the industry—agricultural burning and dust during harvest. Again working in the southern San Joaquin Valley and supported by the California

Almond Board, we tested various RDI regimes ranging from water savings of 15 to almost 50 percent of potential orchard ET. We showed that mild stress over most of the season can be imposed with little negative influence on production and substantial water savings. However, a potentially more significant finding involved the RDI regimes that imposed moderate to severe preharvest (April to July) stress. These strategies reduced vegetative growth (canopy size) and individual kernel weight but had no influence on fruit load; the smaller, more compact trees had higher fruiting density (nuts per unit of canopy volume) than fully irrigated trees. Thus, one could increase the planting density (trees/acre), thereby increasing total nut production (number/acre) compared with conventionally planted and irrigated trees. The downside is that fruit size would be lower, which may somewhat decrease the value of the nuts. On the other hand, the need to prune trees would be much less, reducing the amount of pruning and burning.

Figure 2
Production and Revenue Functions for Applied Water Using Mean 1998 - 2000 for Navel Oranges (Frost Nuccellar) in Southern San Joaquin Valley



Growers currently mechanically shake trees at harvest and leave the nuts on the ground to dry for 7 to 10 days before they are swept up. The sweeping and mechanical collection can create dust and related health concerns. Our research showed that preharvest stress can accelerate hull splitting, allowing for an earlier harvest, which benefits growers in a number of ways; earlier hull split allows the nuts to dry more completely on the tree prior to mechanical tree shaking. We believe that this presents the option of growers harvesting directly from the tree into nut catching machines, as is done currently in pistachio and prune orchards. This would eliminate the dust and other problems associated with nuts drying on the ground, such as ant damage and soil-borne bacteria infection.

Winegrapes is another crop where stress can substantially improve fruit quality. The irrigation of winegrapes was against the law in some European countries, such as Spain, until recently because of real or perceived negative irrigation-related impacts on wine quality. Some stress, however, is beneficial as it can reduce berry size, thereby increasing the ratio of skin to fruit volume. This is important to wine makers since the skin contains constituents important in wine color, taste, and chemical make-up.

| Crop | Bearing Acreage (acres) | Estimated Savings (inches) | Range of Water Savings (acre-ft) |
|------------------|-------------------------|----------------------------|----------------------------------|
| Almonds | 530,000 | 8 to 14 | 424,000 to 618,000 |
| Winegrapes | 480,000 | 8 to 12 | 320,000 to 480,000 |
| Citrus | 244,000 | 6 to 8 | 122,000 to 163,000 |
| Pistachios | 78,000 | 10 to 12 | 65,000 to 78,000 |
| Prunes | 76,000 | 6 to 12 | 38,000 to 76,000 |
| Peaches | 70,000 | 4 to 8 | 23,000 to 47,000 |
| Olives | 36,000 | 6 to 10 | 18,000 to 30,000 |
| Apples and Pears | 49,000 | 4 to 8 | 16,000 to 33,000 |
| Walnuts | 196,000 | Unknown | Unknown |
| Total | 1,759,000 | 52 to 84 | 1,026,000 to 1,525,000 |

Using our research and that of others and conservative estimates of current practices in orchards and vineyards, we have calculated a range of water savings for the major tree crops and winegrapes in California. These estimates are based on RDI regimes that do not reduce grower profits. One tree crop, walnuts, is excluded since we have no data showing that RDI can be successful although further research is planned. Water savings on the low end, those that we believe are currently achievable, total about 1 million acre-feet (see Table 1). If we include RDI adoption coupled with adjusted horticultural practices, such as the higher almond density plantings and improved, more precise methods of identifying tree stress, we believe that 1.5 million acre-feet can be saved. We are currently conducting research on developing electronic sensors that can accurately detect tree stress thus allowing the management of RDI strategies with precision and without risks. Today's farming economy has resulted in the steady conversion of relatively low-value row crop land into higher profit orchards and vineyards. This process only enhances the scale of potential RDI adoption. Achieving the promise of RDI depends on growers recognizing the benefits of managed water stress. This requires demonstrating on a large scale that RDI can be successful in their terms—profits are maintained or increased—and that the higher level of irrigation management required is within the ability of on-farm personnel. We believe that RDI in orchards and vineyards could be a key component in this state's effort to meet the growing demand for water and at the same time, preserve and protect permanent crop production.

Data and Tools

| | |
|---|----|
| Committee on Long term Analytical Tool and Data Development (<i>California Water and Environment Modeling Forum</i>) | 3 |
| Future Quantitative Analysis for California Water Planning, <i>Ken Kirby</i> (SKS Consultants) | 13 |
| Irrigation Survey – Data Analysis, <i>Morteza Orang, Richard Snider, Scott Matyac</i> (<i>Department of Water Resources and University of California Davis</i>) | 23 |

Draft Interim Report

Committee on Long-term Analytical Tool and Data Development

California Water and Environment Modeling Forum

22 April 2004

Committee Charge

“The Committee will draft a “white paper” on strategic planning for analytical tool and data development and use for the management of California’s water supply system. The contents of the white paper will range from a proposed statement of common principles to a proposed strategic vision for development and use of analytical tools and data for the coming 10 years. An interim progress report will be submitted to the CWEMF Steering Committee and the California Water Plan staff and Advisory Committee by April 15th, 2004. A more substantial draft report will be presented to the Steering Committee by June 20, 2004, to allow submission as a comment on the public review draft of the California Water Plan Update.”

- resolved at the CWEMF Steering Committee meeting on March 19, 2004

Problem Statement

In the past, California’s water problems were those of water resource development – locating and sizing of dams, canals, and pipelines and establishing water delivery contracts for major water projects, usually under the control of a single agency. Inexpensive water supplies were being developed for a growing agricultural economy and increasingly prosperous and populous urban areas. Water was seen as being available in streams, but was merely in the wrong place at the wrong times to satisfy these growing water demands. Many of our major analytical tools and data sets are based on of analytical methods designed to address such water resource development problems.

California’s water problems have evolved substantially in recent decades. As most of the inexpensive water supplies have become developed, remaining locations for reservoirs or reservoir expansions are typically less economical or more controversial in terms of environmental impacts and area-of-origin concerns. At the same time water demands and regulations for urban and environmental water uses continue to grow, and substantial water scarcity for agriculture remains.

Responding to the decreasing cost-effectiveness and increasing controversy of traditional water resource development, local, regional, state, and federal agencies have sought to develop additional water management options such as improvements in water use efficiency, conjunctive use of surface and ground waters, coordinated operation of reservoirs and pumping facilities, water markets, transfers, and exchanges, and wastewater reuse. *[There is a suggestion to begin the problem statement here.]* Effective water system management to meet California’s increasingly diverse and geographically dispersed water management objectives requires careful coordination of these new options with traditional water management strategies. The technical aspects of water policy, planning, and operations have become much more complex.

The institutional aspects of water management also have become more complex in recent decades. Water projects rarely operate in isolation, and must increasingly operate in coordination with environmental regulations, water contractor decisions, and the operation of other water projects. Local water management activities such as water use efficiency, wastewater reclamation, water purchases and sales, local conjunctive use must be increasingly coordinated with other local agencies (which are buying or selling water or water storage) and the large water project operations to provide deliveries of water. In recent years, local and statewide water management institutions have shown increasing flexibility to coordinate their water planning and operations decisions.

The involvement of an increasing number of parties and interests in water management has raised the level of scrutiny and expectations regarding quality, accuracy, and reliability of technical information supporting these types of water management decisions and institutional interactions. The increasingly pluralistic, complex, and flexible nature of water management in California also poses challenging demands for technical analysis needed to support such increasingly desirable operations. Recent legislation has resulted in modeling results taking on an accounting function for assurances of local water supplies required for new urban developments that requires invites greater scrutiny of modeling results.

All these issues indicate a need to develop some sort of strategic analysis framework to guide and coordinate the future development of analytical tools and data to support water resources management planning and policy. What analytical and data analysis framework should we strive towards to be most effective in helping to address California's long-term water problems? How should such technical analysis be developed and performed to support the increasingly difficult and controversial policy, planning, and operational decisions at local, regional, and statewide levels for California's water system and its component sub-systems?

CWEMF Effort

In response to recognition of a need to develop a strategic analysis framework to guide and coordinate the development of analytical tools to address a future of increasingly complex water management issues, the members of the California Water and Environmental Modeling Forum (CWEMF) have embarked on a reflective study to identify the major future issues that the California water community will need to address in the next to 10 years and what the types of analytical tools and data that will be needed to support water policy, planning, and operations decisions 10 years into the future. A 10 year time frame was felt necessary to 1) concentrate our thinking on the kind of technical environment which would be of the greatest long-term value (rather than the current problems du jour) and 2) reduce adherence to existing technical tools which are unavoidably somewhat legacies of past problems. While the results of this work might be informative and useful for current planning and policy deliberations, we are expressly focused on developing a long term vision of the future. The purpose of this effort is to prepare a vision of how our work might be more effective and efficient in providing a stable and constantly improving information basis for making water management decisions and policies. As such, we would like to provide a structure for long-term thinking about technical analysis of California's water problems, and perhaps an objective to strive towards in the coming years.

The process of this CWEMF effort began with a wide-ranging discussion at the February 2004 annual meeting of CWEMF at Asilomar. This plenary session led to the solicitation of input on strategic modeling directions from the CWEMF membership and others, based on four open-ended questions and the formation of a Committee on Long-term Analytical Tool and Data Development. This committee will

continue with its solicitations of ideas from the water community, will sponsor one or more workshops and otherwise consult broadly on these issues, and prepare written products which constitute a future vision of the technical analysis capability desirable for addressing California's long-term water problems.

This interim report is an initial step in this study, posing a set of common principles for analytical tool and data development and use that should apply across all major analytical tool and data developments and applications. It is felt that having a set of common principles for major developments and applications will provide a common foundation for both technical activities and decision-maker use of information provided by technical activities. A set of common principles should provide conceptual expectations for technical work which technical analysts, water managers, and policy-makers can all understand.

Common Principles for Long-Term Analytical Tool and Data Development and Use

Similar to the "Principals for California Water Planning Analysis," found in the California Water Plan Update Bulletin 160-03 DRAFT (Appendix A of this document), we suggest XX principals of near-universal applicability for long-term technical analysis tool and data development and use for California water problems. These principles fall into 5 areas and are summarized in Table 1. While the exact vision of desirable technical analysis capability is as yet unclear to us, we feel such principles can help structure our long-term technical thinking, provide linkages between our technical work and water managers, policy-makers, and stakeholders, and provide some direction to help move our data and tools from what we have today to what we would like to have in the future.

Strategy

1. Analytical tools and data should be developed based on expected long-term water problems and the decision-making processes they are expected to inform.
2. Frequently amended strategic documents should identify the technical objectives, roles, and responsibilities of major data collection efforts and analytical tools.
3. A frequently updated implementation document should outline short-term and long-term efforts, budgets, and responsibilities for continuous improvement of analytical tools and data with policy for continued user, local agency, and stakeholder involvement.
4. DWR, in discussion with other major stakeholders, should maintain a strategic analysis framework that should undergo periodic internal and external review to identify needs for additional analytical tool and data development.

Analytical tools and data are expensive to create and maintain. Such tools are more likely to be successful if they are designed to respond to a defined set of problems and decision-making processes perceived to be of long-term importance. Strategic planning documents for analytical tools provide evidence and documentation of such thinking, as well as a measure of transparency of the intent of analytical tools for the non-technical community. However, since problems, data, understanding, and analytical techniques change with time, so it is best for strategic thinking to be adaptive and amended from time to time.

Aside from the value of informing policy-makers and managers of the intent of particular analytical tools, such documents and thinking provide a basis for better long-term convergence between the expectations of modelers and model result users. Another important aspect of strategic documentation is to educate

newcomers to the technical community, so that they might more quickly understand the tools, their limitations, and , the context of their application.

Someone must be responsible for strategy, or it will not happen. Strategic responsibility also seems ill-fitted to a grass-roots volunteer organization, such as CWEMF. The California Department of Water Resources, through its responsibilities for statewide water planning and accounting, seems the most logical agency for maintaining a strategic analysis framework, although it would probably be wise for DWR to accomplish this function in broad collaboration.

Transparency

5. All data and models should have significant documentation.
6. Known limitations and appropriate applications should be documented.
7. Model applications should have explanatory and self-critical discussions of results.
8. All data, models, and major reports should be in the public domain and available on the web.
9. A common glossary of key terms should be maintained.

Analysis of water systems as complex and extensive as California's will never be wholly transparent. No one person can understand this entire system, so it seems unrealistic for any one person to understand a set of analytical tools and data which might reasonably represent such a system. Nevertheless, greater and more systematic efforts at transparency in technical activities are needed to:

- a. **Enhance quality.** Transparency allows analytical methods better understood, allows limitations to be more readily identified and addressed, and facilitates broader input into improvements.
- b. **Enhance credibility.** Technical credibility rests on the notion that each step in the analytical process has an empirical or derived basis and that each of these steps is discoverable, testable, and replicable.
- c. **Enhance sustainability.** Personnel in technical positions frequently change positions, and the most experienced eventually retire from service. Analytical tools and their data sets are often very long-lived. Without systematic and detailed documentation, the basis for analytical capability can be lost, detracting from the ability of new personnel to understand what they are doing technically, resulting in an inability to improve or adapt analytical tools and data for current or future conditions, and deteriorating the empirical and derived basis for the model's results.

Self-critical discussion of a model or model results is essential to making useful and credible insights from unavoidably imperfect model results

Technical Sustainability

10. Modularity: Major analytical tools should be designed and implemented to fit modularly, which allows models to be tested, refined, updated, and replaced without major adjustments to other components, in the larger strategic analysis framework
11. Adaptive information management framework: Major data and information efforts should fall within a larger information management framework, including protocols for data documentation and updating, and documentation of limitations.

The complexity and ever-changing nature of California's water problems calls for a long-term approach where major tool and data developments can remain integrated but adaptable over long periods of time. In a strategic modeling framework, individual models are modular in that they are explicitly (and painfully) designed to have consistent assumptions and data structures (time-steps and spatial

aggregation). Within each model, spatial components are also modular, allowing models to be run as detailed and spatially extensive representations, regionally detailed representations, or extensive simplified representations for different purposes. Modularity allows one element of an analytical framework to be improved significantly without attempting to revolutionize all aspects of modeling such a complex system. Modularity also should facilitate creation of analytical capability that can be applied at coarser or finer spatial, temporal, or topical scales.

Just as models need to adapt over time, so does the data used for modeling. This is more easily and reasonably done if data is developed within a larger systematic framework for system analysis. Because data is expensive, current modeling is limited by the data remaining from historical technical activities. Some effort and investment is needed to develop and document the kinds of data needed for long-term future analytical activities.

Many of the transparency principles are also related to technical sustainability. The coverage principles below also would facilitate greater job flexibility of personnel statewide.

Coverage:

12. The spatial coverage of the basic data and analytical framework should be statewide and encompass a wide variety of water management options and processes.
13. Local and regional water management and resources should be explicitly represented to allow consistency of local, regional, and statewide studies.

Water management problems in California have become highly interconnected, and are likely to become increasingly so. Conjunctive use and water conservation efforts in one end of the state are increasingly tied to water use decisions in another, with potential implications for many water management components in between. For detailed analysis, a statewide framework of analysis is desirable.

Development of statewide coverage must be a cooperative enterprise. If each local, regional, and statewide agency employs a consistent data and modeling framework and set of modeling protocols, an entire analytical system can be constructed without major funding and expertise from statewide agencies beyond developing the framework and protocols. Having a statewide framework also provides a standardized and more credible basis for water management studies for local and regional projects as well as opportunities for local agencies and concerns to become involved with improving representation of their areas for regional and statewide analysis.

Accountability and Quality Control:

14. Explicit model testing should be undertaken, documented, and made available for major analytical tools.
15. Major analytical products should undergo review by external unaffiliated experts and local agencies whose systems are included in the model(s).
16. Protocols and guidelines for model use should be developed and adhered to.
17. In developing and maintaining analytical tools, significant efforts should be made to involve local agencies and stakeholders, including users groups or other cooperation mechanisms for widely used analytical tools.

Quality control is an essential part of good technical work. And much of how the public and policy-makers come to understand the presence of quality control in technical work is through formal testing, documentation, application, and review procedures. Such formalities may not always be needed (or required), but they are likely to be especially desirable for studies of controversial subjects, where there is a significant probability of serious questioning of analytical results and tools.

Table 1:
Suggested Principles for Development and Use of Analytical Tools and Data for California Water Problems and Solutions

Strategy:

1. Analytical tools and data should be based on expected long-term water problems and the decision-making processes they are expected to inform.
2. Frequently amended strategic documents should identify the technical objectives, roles, and responsibilities of major data collection efforts and analytical tools.
3. DWR, in discussion with other major stakeholders, should maintain a strategic analysis framework that should undergo periodic internal and external review to identify needs for additional analytical tool and data development.

Transparency:

4. All data and models should have significant documentation.
5. Known limitations and appropriate applications should be documented.
6. Model applications should have explanatory and self-critical discussions of results.
7. All data, models, and major reports should be in the public domain and available on the web.
8. A common glossary of key terms should be maintained.

Technical Sustainability:

9. Modularity: Major analytical tools should be designed and implemented to fit modularly, which allows models to be tested, refined, updated, and replaced without major adjustments to other components, in the larger strategic analysis framework
10. Adaptive information management framework: Major data and information efforts should fall within a larger information management framework, including protocols for data documentation and updating, and documentation of limitations.
11. A frequently updated document should outline short-term and long-term efforts, budgets, and responsibilities for continuous improvement of analytical tools and data with policy for continued user, local agency, and stakeholder involvement.

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17. In developing and maintaining analytical tools, significant efforts should be made to involve local agencies and stakeholders, including users groups or other cooperation mechanisms for widely used analytical tools.

Implementation of Common Principles

Long-term adherence to such principles will require long-term focused and planned investments beyond project-specific studies. Adherence to these principles will also require management commitment from the major agencies involved in analytical studies of California's water, especially, but not exclusively, the California Department of Water Resources and the US Bureau of Reclamation.

Why might the diverse agencies and consultants involved in technical analysis of California's diverse water problems for diverse stakeholders and purposes abide by such a set of common principles?

Several reasons to cooperate and mechanisms for cooperation seem plausible:

- *Improvements in internal modeling effectiveness and efficiency by agencies and consulting firms* – Many of the principles above are simply sound ideas for improving the sustainability and effectiveness of technical activities in the current California water management environment. The principles are good business practices, made all the more effective and efficient as more modeling activities abide by them.
- *Predefined rules and procedures* – Having predefined rules and mechanisms for addressing technical conflicts will increase the ability of agencies to perform consistent analysis. This will save staff resources in the long term by allowing more efficient resolution of technical differences.
- *Common professional expectations* – Adhering to broadly useful norms and facilitates cooperation among agencies.
- *“Peer pressure”* – It is more difficult and expensive to cooperate with agencies not employing a common analytical framework.
- *Common agreement* – Common agreement could be informal or might be a formal agreement, perhaps similar to the MOU on urban water conservation BMPs that are the basis for the California Urban Water conservation Council.
- *Legal or regulatory requirements* – Adherence to such common principles can have a legal or regulatory basis if they become the expectations of judges ruling on the adequacy of EIS/EIR documents or are mandated in SWRCB water right regulations, DWR requirements for use of SWP facilities, legislated for access to State funding. SWRCB already requires peer review of some technical products [Rich S., Can you help here?].

Not all of these mechanisms would be available, appropriate, or even perhaps productive to pursue at this time.

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Appendix A: Principles for California Water Planning Analysis Development and Application of Tools and Data (from Bulletin 160-03 DRAFT)

Strategy:

1. Emphasize the approach “First what, then how.”
2. A frequently amended strategic document will lay out DWR’s strategic analysis framework and identify the technical objectives, roles, and responsibilities of major DWR data collection efforts and analytical tools and their interactions and their responsible managers.

Transparency:

3. Develop and maintain a glossary of key terms.
4. All data and models should be in the public domain and available on the web.
5. All data and models should have significant documentation.
6. Known limitations should be documented.

Long-Term Viability:

7. Modularity: Major analytical tools will be designed and implemented to fit modularly, which allows models to be tested, refined, updated, and replaced without major adjustments to other components, in the larger strategic analysis framework
8. Adaptive information management framework: Major data and information efforts will fall within a larger information management framework, including protocols for data documentation and updating, and documentation of limitations.
9. A frequently updated document will outline short-term and long-term efforts, budgets, and responsibilities for continuous improvement of analytical tools and data with policy for continued user, local agency, and stakeholder involvement.

Coverage:

10. The spatial coverage of the basic data and analytical framework will be statewide.
11. Local and regional water management and resources will be explicitly represented.

Accountability and Quality Control:

12. In developing analytical tools, significant efforts should be made to involve local agencies and stakeholders. Users groups will exist for major analytical tools.
13. Major analytical products will undergo review by external unaffiliated experts and local agencies whose systems are included in the model(s).
14. DWR’s strategic analysis framework will undergo periodic internal and external review to identify needs for additional analytical tool and data development.

Future Quantitative Analysis for California Water Planning

Background and Context

Past California Water Plan updates were intended for water managers and those involved in making state water infrastructure decisions. However, as various resource issues become more interconnected, and land use and resource planners consider water management in their analyses and decisions, requests are increasing for the Water Plan to address questions broader than traditional water needs.

Analytical tool and data development for California has not kept pace with the growing public awareness of the complexity and interaction between water-related issues. Deficits exist in current analytical capability related to supply reliability and systems issues. A critical issue facing California is the need for better data and tools to produce useful information about *environmental objectives, water quality, economic issues, equity issues, and ground and surface water interaction*. Also, there is a need to better integrate details associated with regional and local planning into the studies being conducted from a statewide perspective. For planning purposes, these tools and data must help planners predict a range of plausible future conditions and interactions on the statewide level and compare outcomes of potential management actions. Many of the current tools have been developed and applied in a comparative role, and their suitability for a predictive role can vary widely. Even so, planners rely on the state to provide data and outputs that help to describe and analyze plausible future scenarios, which they can use for planning purposes.

The State must play a leadership role in developing the overall strategy for California water management from a system-wide perspective. No tools currently exist that can be used for both predictive and comparative modes integrating all of the interactions described above. Local land use planners also rely on water management information for which the State can provide insights. Work on the Water Plan is converging with the CALFED Integrated Storage Investigation's Common Assumptions and Water Use Efficiency Comprehensive Analysis studies. Staff from these planning processes have been meeting to coordinate information management and discuss study assumptions and quantitative methodologies.

Advisory Committee members, stakeholders interested in modeling, technical consultants for other planning processes, California Bay Delta Authority and State Water Project staff, and DWR staff have met more than 16 times as the "Modeling Work Group" to discuss the roles, validation, and confidence in available tools and data and the ability to perform studies and analyses envisioned for Update 2003. To address concerns, a series of workshops were convened that focused on the fundamental questions the Water Plan should address in general and the technical information that the tools are expected to provide in particular. Many of the issues discussed are responded to in the work plan, including quality assurance, transparency, accessibility of information, external review processes and integrating issues like water quality, economics, the environment, groundwater, and land use.

Principles for California Water Planning Analysis Development and Application of Tools and Data

Strategy:

1. Emphasize the approach “First what, then how.”
2. A frequently amended strategic document will lay out DWR’s strategic analysis framework and identify the technical objectives, roles, and responsibilities of major DWR data collection efforts and analytical tools and their interactions and their responsible managers.

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14. DWR’s strategic analysis framework will undergo periodic internal and external review to identify needs for additional analytical tool and data development.

The short and long-term work plan prepared for Update 2003 aims to improve the quantitative understanding of California water and of how to employ analytical tools to aid in developing and comparing solutions to California’s water problems and decision making. This work plan for data and tools is consistent with the three-phased approach for producing California Water Plan Update 2003, outlined in Chapter 1. The work on tools and data in the three-phased approach include:

- Phase 1: Recommend the short- and long-term work plans.
- Phase 2: Select appropriate analytical tools, data, and assumptions to provide technical analyses needed to evaluate the four plausible future scenarios (described in the prior section).
- Phase 3: Apply the analytical tools selected in Phase 2 and interpret results to evaluate performance of several response strategies on a regional basis given the four plausible future scenarios.

Technical Information Needs

The desire to address various crosscutting issues such as environmental objectives, land-use planning, and economics in different scenarios in this Water Plan and other ongoing planning efforts requires more technical and quantitative information than for previous Water Plans. Many discussions with the Modeling Work Group and the Advisory Committee have focused on the specific information needed to satisfy the broad objectives of the Water Plan’s new planning framework (see Chapter 1) and disclosure of all technical assumptions.

In addition to developing the new planning framework, the Advisory Committee and DWR invited land use and resource planners, academics, policy analysts, and technical experts to build on and affirm Advisory Committee understanding about issues critical for the Water Plan to address. These conversations have been captured in mind maps that represent a web of relationships and ideas. The mind maps are in the Technical Guide (Volume 4). In addition to traditional needs related to projecting water supply and demand, Water Plan users seek good information related to ecosystem wants and demands; economic issues, such as tiered water pricing and the effect on demand or economic effects of transfers; water quality, such as reusing wastewater and matching water quality to use; equity issues, such as public trust and environmental justice concerns; water use efficiency; and ground and surface water interaction. Further, the Water Plan could play a critical role linking water and land use management decision making. Land use planners need useful information about water demand as it relates to compact development and growth.

Types of technical information needs that have been identified can be described as:

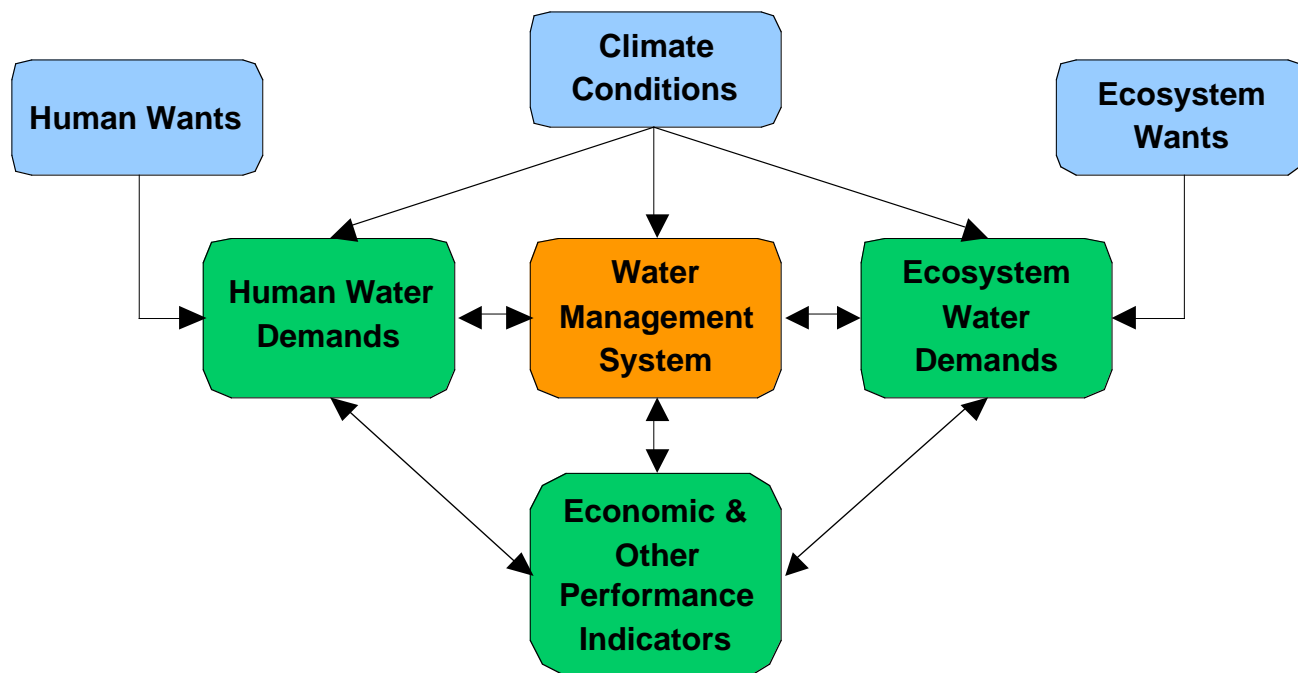
- **Data** – factual (or observed) information, such as measurements or statistics (e.g., gauged flows in a river, population as measured by census, and salinity of a water sample). Sets of data can be *raw* (as taken from measurement device) or *elaborated* (modified slightly as part of quality assessment and quality control measures, or supplemented to address missing measurements).
- **Relationships** (or system interactions) – descriptions of how the social, physical, and environmental systems affect or are affected by the status of water supply and water use in California (e.g., how releases from a reservoir affect water temperature at a point in a river downstream, the crop mix in a region and the expected market conditions for each crop, and snow pack conditions in February and the delivery of SWP water).
- **Estimates** – inferred, derived and/or forecasted quantities based on available data, defined relationships, and other assumptions (e.g., population forecasts for the Los Angeles area in 2030, groundwater flows between sub basins, future available water deliveries, and the cost to implement water conservation best management practices).

Organizing Information

Given the large quantity and complexity of data, relationships, and estimates desired, the update team has organized the requested information according to their potential interactions. Figure 3.X illustrates a high-level conceptual model (framework) of the interactions. The three light blue boxes across the top represent information set by the user and does not change during the analyses, such as population, population density, and hydrology. (These can be called *static* estimates.) The three green boxes contain information that will be quantified using analytical tool(s) that explicitly consider the inter-relationships with other data, relationships, or estimates (or *dynamic* estimates). Examples of dynamic estimates include: demand for agricultural water supply, the economic costs of drought management, etc. The orange box in the center represents where most of the decisions are made within the analytical tools (often called decision variables). This box would contain most of the information contained in a response package. A priority list of technical information needs is in Volume 5 the Technical Guide.

•

Conceptual Framework for Data and Estimate Interactions



Planned Analyses

For Update 2003, the phased work plan includes three groups of analyses:

1. **Water Portfolios** that describe the available water sources, movement and uses by region, under several recent hydrologic conditions using actual data for 1998, 2000, and 2001. The portfolios present historic *data* and the *relationships* between sources and uses of water as it moves in California.
2. **Future Scenarios** that describe plausible conditions of water use, supply, and demand throughout California in 2030. The scenarios are intended to provide quantitative *estimates* of future water conditions based on existing *data* and defined *relationships*.
3. **Performance Comparison** of different water resource management strategies combined to form response packages applied to the future scenarios. A list of evaluation criteria (*estimates*) that must be generated to compare the performance of different water management strategies is shown in Volume 3.

Water Portfolios

The *water portfolios* provide comprehensive water balance and flow diagrams for 10 hydrologic regions covering the entire state. The flow diagram characterizes the hydrologic cycle and documents sources of water, such as precipitation and inflows into the state, and tracks the water as it flows (through many different uses) to its ultimate destination. Since data for some categories are not measured for many

regions of the state, the current water portfolios show gaps. Identifying additional data collection and management activities in Update 2003 is an important step in improving the water portfolios for future water plan updates.

There are a number of categories in the flow diagram where data are simply not available or very resource intensive to compile. Significant data gaps include:

- state wide land use data (e.g., native vegetation, urban footprints, non-irrigated agriculture, and irrigated agriculture)
- total groundwater natural recharge,
- groundwater subsurface inflow and outflow,
- groundwater extractions and recharge,
- evaporation from land surfaces,
- evapotranspiration from native vegetation and non-irrigated agriculture,
- total stream flow,
- total direct diversions,
- natural and incidental runoff,
- return flows and
- conveyance losses.

There are a number of data items necessary to calculate or estimate these categories. Some of the major data items needed to complete the flow diagram and water balances consist of more detailed and accessible land and water use information including information to separate out applied water use versus consumptive water use. The major data items are:

- water source of supply information,
- outflow data,
- groundwater level data,
- groundwater recharge rates,
- natural riparian water requirements,
- evapotranspiration rates for all types of vegetation,
- detailed return flow information and
- more detailed physical information about all watersheds, water systems and groundwater basins in the state.

Data are currently available for some regions and not for others. For example, methodologies and data to estimate natural runoff are available for regions like the Sacramento River and the San Francisco Bay Region where the Delta is a control point, but in areas like the South Coast Region with no control point and substantial groundwater, the natural runoff is nearly impossible to estimate. In addition to natural obstacles, existing data are not easily aggregated or disaggregated to provide convenient access for all areas of interest, and resource constraints limit extensive data collection and management necessary to quantify and track all the water in the state.

The state should guide California in expanding data collection and management programs that already exist. Data needs are characterized by the need for detail (data monitoring in more geographic locations and for particular categories), to digitize (common electronic methods), and for a comprehensive database.

Future Scenarios

Developing quantitative estimates for four *future scenarios* requires using available data and presumed relationships. A list of key factors affecting future use and supply scenarios in 2030 is shown in the Technical Guide (Table 1). Some examples of these factors include total population, population density, agricultural water use efficiency, and energy costs. Each of these factors must be predicted or quantified, and like the data needed for the water portfolios, the availability and resolution of data needed for the future scenarios varies widely. While the key factors have been identified, much work still exists to reach agreement on the relationships between the factors and the methods that will be used to quantify the factors as described in Table 1. Some examples of the significant complexities in predicting factors such as groundwater storage or surface water storage conditions in 2030 are shown in the Factor Complexity Diagrams in the Technical Guide.

A report addressing some of the challenges and possible approaches for forecasting urban water demand was presented in July 2003 entitled *Water Demand Forecast Methodology for California Planning Areas: Work Plan and Model Review*. (See Technical Guide.) The authors of the report offer recommendations for:

- near-term analyses given available data, and
- future development for long-term analyses.

The recommendations for future development identify additional data needs such as:

- water and sewer rate data for the utilities and time frames for data contained in DWR's Public Water Supply Survey database,
- correlate local/regional demographic information with per unit water use rates by area, and
- correlate climate conditions with per unit use rates over time.

This new information will allow DWR to update their statistical explanatory demand models by region based on some of these key factors. DWR will have to examine other factors and determine the best way to quantify those factors. DWR predicts that other data gaps will emerge leading to better understanding of the type of data collection and analysis needed to support the new planning framework.

Performance Comparison

A significant difference in the new Water Plan framework is the addition of quantitative comparisons for thematic response packages of water resource management strategies (as identified in Volume ?). This *performance comparison* of various mixes of water management strategies under plausible future scenarios will provide planners unprecedented access to relevant technical information and new insights. This quantitative insight can be used to help guide investments in statewide water management actions. To help focus the quantitative analyses, a list of evaluation criteria have been identified with the Advisory Committee and Modeling Work Group that represents the technical information required to compare the response packages. A full list of the evaluation criteria are included in the Technical Guide. These evaluation criteria include information such as:

- percent of years agriculture receives all of its desired water supply
- change in economic benefits or losses
- statistical water supply reliability by location
- change in regional imports and exports

While this information is expected to be extremely valuable, developing the capability to complete these performance comparisons presents a significant challenge for DWR over the next several years. Conducting quantitative performance comparisons that the Advisory Committee and public want will require considerable resources (staff, time, and money) to develop and implement.

Analytical Tools

Generating quantitative estimates for most of the information contained in the water portfolios, future scenarios, and performance comparison requires the use of one or more analytical tools. The term *analytical tool* is defined to mean “something used to study or determine the nature and relationship of the component parts of a whole”. Given the broad range and scale of quantitative information desired, many analytical tools will be needed. No single analytical tool could be developed to provide all of the desired information, but rather a hierarchy of tools must be employed.

The role of an analytical tool and the method for using it varies significantly depending on the specifics of the information being generated. Given the desire to promote understanding and transparency of analysis, the Update team has developed and will apply a systematic method to identify potential analytical tools, determine their proper use, and validate their application to generate all of the quantitative information needed for the Water Plan.

Initially, this effort will focus heavily on the need, availability, and adequacy of technical tools to perform the integrated analyses. Given the high degree of interest expressed by several members of the Advisory Committee and the Modeling Work Group, DWR proposes a systematic, step-by-step approach to develop acceptable methods to complete the quantitative analyses for both the short-term (Update 2008) and long-term efforts. This step-by-step approach is outlined below, and will require extensive participation from the Modeling Work Group.

Once the methods have been defined and agreed upon, DWR will need to set up and conduct the modeling studies, perform quality control reviews of modeling results, and interpret and communicate the meanings of the analytical tool outputs.

Framework to Assess an Analytical Tool

Evaluating the appropriateness of an analytical tool to produce quantitative estimates can be extremely complicated. To help make the process as effective and transparent as possible, the team will apply the following framework, described using a series of questions, for each item on the comprehensive list of technical information needs.

- What is the job at hand?
 - Describe by task if needed, highlighting the quantitative results that would assist in accomplishing the task
- If the ideal tool to assist with the task were available, what capabilities would it have?
- Which tools are available that could produce the desired quantitative results?
- Which tool represents the best fit?
 - Evaluate the potential tools according to the desired capabilities
 - Consider limitations
 - Consider practical ability to improve each tool
- What are the remaining limitations of the selected tool likely to be?

This process can be improved by using common, objective evaluation criteria to the extent possible for each piece of technical information being generated. The criteria used to answer the question “Which tool represents the best fit?” will be discussed and documented before making any judgments about the suitability of the analytical tools in question.

Parts of an Analytical Tool

To understand the capabilities of an analytical tool, or to assess the validity of using an analytical tool for a specific purpose, it is helpful to consider the tool in terms of its parts:

- Conceptual model: a description or analogy used to visualize something that cannot be directly observed (e.g., a road map).
- Theoretical model: a system of postulates, data, and inferences presented as a description of an entity or state of affairs (e.g., the law of gravity).
- Numerical model: an analytical tool that employs quantitative approximations to the solutions of mathematical problems.
- Data
- Data management system
- Software
- Administrative aspects: intellectual property (proprietary vs. public domain, user support, expertise available in community to use or improve model, etc).

Describing an analytical tool using these categories promotes more precise discussions regarding the capabilities and appropriate use of analytical tools.

Information Management System

The quantitative elements of the water plan require tremendous amounts of data and information. As such, effective management of this information is a key component to the long-term success of the technical efforts. Currently available information management system technologies could be used to provide efficient, secure, and transparent access to this critical component of the ongoing state wide planning efforts.

However, the technology alone is not sufficient. A necessary part of a successful information management system is an intelligent information management framework and scheme. Ideas for a viable information management framework can be developed as the needed data, relationships, and estimates for the quantitative analyses are further described.

Resources Needed

Generating and interpreting the quantitative information described above will require persistent dedication of significant resources. The technical scope and magnitude of the desired analyses is unprecedented in California water planning. While several parts of the desired analyses have been done before, no previous quantitative study has ever been conducted so comprehensively and with such intensive stakeholder interaction. Needless to say, a large team of technical experts with diverse skills will need to be engaged over a lengthy period of time. Technical experts will be needed who can understand the complex interaction between policy-making and technical analyses, organize technical information needs, identify and qualify subject-matter data, manage extensive data, interface with diverse stakeholders

and programs like the California Bay Delta Authority, and demonstrate leadership to inspire confidence within policy and technical communities. In addition to the broad array of technical expertise required, a large number of experts will need to be assembled to accomplish the goals set forth in the given timeframe. Nonetheless, DWR is committed to leading the way in developing the methods, analytical tools, and conducting the analyses to provide the information the public of California needs in a transparent and responsive manner. Some examples of existing analytical tools and data systems that incorporate some aspects of the vision for desired quantitative capability include Metropolitan Water District's IRPSIM, CALVIN, Aquatool (Spain), and SCADA systems (common for most major urban water distribution systems).

Major Tasks and Schedule

The following tasks and associated schedule chart outline the major steps DWR plans to take to provide the desired technical information in a timely manner. As shown on the associated schedule chart, DWR plans to perform these activities with frequent and detailed interactions with interested parties through the Modeling Work Group. This framework requires that DWR receive assistance from others to complete the tasks. The rate of progress will depend on available resources and the level of cooperative participation by other agencies and institutions. This systematic approach will allow DWR and others to address concerns raised about validity of existing tools and questions raised about the appropriateness of quantitative methods used for previous technical studies. A related item, the peer review of the CALSIM II model being conducted in cooperation with the California Bay-Delta Authority is shown on the schedule.

1. Generate a priority list of required technical information.
2. Organize the technical information needed using the relationships of the information similar to the conceptual framework illustrated in Figure 3.X.
3. Circulate the priority list of required technical information to the Modeling Work Group for review. Meet with the MWG to discuss.
4. Incorporate comments and finalize priority list of required technical information.
5. Propose a conceptual model (or models) for each piece of information needed to complete the:
 - a. Water Portfolios
 - b. Future Scenarios for 2030
 - c. Performance Comparisons
6. Distribute documents containing the proposed conceptual models to the Modeling Work Group and conduct workshops to adopt preferred conceptual models used to compute each piece of technical information
7. Propose a theoretical model for each piece of required technical information including: postulates, data, and inferences
8. Establish, to the extent possible, objective criteria for evaluating the suitability of potential analytical tools for generating each piece of required technical information.
9. Distribute documents containing the proposed theoretical models to the Modeling Work Group and conduct workshops to adopt preferred theoretical models used to compute each piece of technical information
10. Compare preferred theoretical models with those implemented in currently available analytical tools
 - a. Review existing analytical tools to determine if they incorporate some or all of the preferred theoretical models
 - b. As needed, determine if existing analytical tools can be modified for short-term use

11. Modify tools as needed and as possible for short-term use
 - a. Make changes to existing analytical tools to better incorporate preferred theoretical model implementation that can be accomplished by the end of Q1 2005
 - b. Acknowledge and document where existing tools and data that will be used for Update 2008 fall short of the desired theoretical implementation and cannot be suitably modified by end of 2007
 - c. Prepare a document that describes how analyses for Update 2008 will be implemented in the short-term
12. Develop a document that outlines requirements for new analytical tools and data to perform the preferred quantitative analyses for future updates
 - a. Describe likely approach to obtain or develop tools that can fulfill the requirements
 - b. Develop a schedule for development and testing
 - c. Develop budget for development and testing
13. Apply existing analytical tools to quantify all required technical information for Update 2008
 - a. Future Scenarios
 - b. Performance Comparison
14. Interpret and describe quantitative results for
 - a. Future Scenarios
 - b. Performance Comparison

Update 2008 and Beyond

The tasks described above are focused towards identifying and developing trusted and acceptable quantitative methods over the next two years that can be applied as completely as possible in the short-term for update 2008, and as close to the preferred methods as possible for updates beyond 2008. As these requirements, data gaps, and preferred conceptual and theoretical models are adopted, DWR will also identify the requirements for a viable information management system. Given the magnitude and complexity of information, and the desire to coordinate and share this information at various levels of detail throughout the state, DWR likely will need to implement an enterprise-level information management system accessible via the World Wide Web.

Furthermore, as progress is made in developing better, more comprehensive data and analytical tools to analyze the water movement and interactions, DWR plans to foster development of decision support tools that increase planners' ability to fully utilize the new and improved technical information being provided in future Updates.

Irrigation Survey

This article is still pending.

Environment

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| Quantification of Unmet Environmental Objectives in State Water Plan 2003 Using Actual Flow Data for 1998, 2000, and 2001, <i>Environmental Defense</i> | 39 |

Considering Water Use Efficiency for the Environmental Sector

Prepared for

**California Department of Water Resources,
Statewide Water Planning Branch**

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May 14, 2004**

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The authors of this report are masters students at the Goldman School of Public Policy at the University of California, Berkeley, and this report fulfills the course requirements of Public Policy 200. The opinions expressed in this report are those of the authors and do not necessarily represent those of the Goldman School, the University of California, or the Department of Water Resources. This study was prepared in conjunction with the 2003 update of the California Water Plan.

Executive Summary

The goal of this report is to provide a starting point from which the water planning community can move toward improving the allocation of water within the environmental sector. To facilitate that process, this report presents:

1. A discussion that highlights the water community's points of agreement on the concept of analyzing the application of water to the environment
2. A term, Managed Environmental Water Use Efficiency (MEWUE), to reflect that concept, and a definition of that term
3. A survey of existing methods that could be used to develop MEWUE
4. Suggestions about how to proceed with implementing MEWUE

Based on our analysis, we found that there was genuine interest in understanding and improving how water is allocated to the environment. The idea of maximizing environmental benefits for a given amount of allocated water is a unifying thread among stakeholder interests. We focus on this idea throughout the report as the central concept that MEWUE is intended to achieve.

We propose a new term to reflect the stated concerns of stakeholders that other terms, Environmental Water Use Efficiency and Ecosystem Restoration Water Use Efficiency, did not fully address. We propose *Managed* to indicate that MEWUE does not evaluate the environment's use of water per se but rather the effectiveness of water in controlled systems. We propose *Environmental* to reflect the range of "uses" of water in the ecosystem, including ecosystem maintenance, restoration, and water quality. Lastly, we support the use of the word *Efficiency* because efficiency communicates the intent of maximizing benefit for a given amount of water, providing a basis for comparison of the benefits obtainable from different uses of that water.

MEWUE: a mechanism to analyze alternative uses of managed environmental water to determine which allocation of a given amount of water will maximize environmental benefits, and a means to improve decision-making over time.

We address the issue of why having an explicit decision-making mechanism is essential. It is hard to allay the fears that some have of incorrectly measuring environmental benefits. However, it is even more difficult to claim that decisions based on implicit measures and beliefs are better for the environment than those based on some imperfect but explicit consideration of environmental benefits.

The new term, MEWUE, and its definition can place stakeholders on the same page. There will be less confusion about what WUE for the environment means and is intended to accomplish. This common ground will allow the investigation of methods to implement MEWUE to move forward.

In addition to outlining a concept, this report explores existing approaches that could play a part in implementing MEWUE. The methods researched fall under two major categories: metrics of ecosystem quality and institutional improvements. Each technique described includes a case study to highlight its implementation and applicability to MEWUE. The metric techniques discussed are:

- Ecological Indicators
- Instream Flow Requirements
- Economic Valuation

The institutional techniques discussed are:

- Benchmarking and Best Management Practices
- Improved Water Management and Collaboration

The two broad categories of methods will probably work best in combination with each other. The technical approaches offer a method for calculating changes to the environment, while the institutional methods are necessary to operationalize the technical methods.

This report suggests further investigation of MEWUE. Our analysis finds that there is enough common ground among stakeholders to warrant further development of MEWUE. Furthermore, there are techniques already in practice that promote the goal of MEWUE and that can potentially serve as methods for successful MEWUE implementation. We hope that this report provides sufficient direction to begin an on-going collaborative process of defining and implementing MEWUE that continually improves the allocation of water within the environmental sector.

Main Conclusions

Maximizing the environmental benefits for a given amount of water is a valuable concept for the California water planning community to pursue. MEWUE is a feasible way to implement this concept. Various techniques applicable to assessing and improving MEWUE are in place or are being developed and could feasibly be adapted for use in a specific MEWUE program.

This report is the first step in a process. We hope it can serve to start a collaborative discussion among stakeholders on how to best implement MEWUE.

1.0 Introduction

Background

Water planning in California has historically been a technically and politically complex process, with many diverse stakeholders vying for access to a limited resource. In the past, the water planning process focused on the agricultural and urban water use sectors. Water scarcity affected these sectors as California grew, which prompted development of efficiency measures to address the problem.

Some believe that it is now time to evaluate whether the environmental sector can and should use its water resources more efficiently. Some stakeholders in California water management believe that since understanding of ecosystem health is improving, opportunities are emerging to enable maximizing overall environmental benefits from any given amount of expenditures – whether in monetary or water terms. Since resources for environmental uses are becoming scarcer as compared to the recent past, policymakers increasingly face the need for a method of evaluating the relative environmental benefits of alternative uses of these resources.

Certain water interests believe that water used for environmental purposes should be held to an efficiency standard similar to those in agricultural and urban sectors. However, some members of the water planning community oppose the idea of implementing water use efficiency (WUE) measures for the environmental sector. Reasons for this resistance vary among stakeholders, but we characterize their concerns broadly to include: a fear that implementing such measures will ultimately take water away from environmental uses; reluctance to put a price on something that some believe should not (and cannot) be valued; and the belief that such measures in the environmental context are inappropriate since some believe the goal of water use efficiency should be to keep as much water in the environment as possible. To date, there is no consensus about whether water use in the environmental sector can or should follow the same path that the urban and agricultural sectors did, or about how to define or measure the efficiency of water used for environmental purposes.

In addition to this lack of consensus between groups, problems also arise regarding the technical feasibility of implementing WUE for the environmental sector. A major barrier to the process is the perceived lack of both a comprehensive way to measure the health and/or value of ecosystems and a method of comparing the relative benefits of alternative water uses. Whether expressed as a single value or as an index of several relevant factors, measuring ecosystem health suggests the use of some quantitative metric of ecological integrity. Such a metric may need to incorporate such diverse factors as chemical water quality, biological species populations, and physical channel structure. Implementing efficiency standards would ideally involve a systematic way to compare the relative benefits of alternative water uses based on these measures of ecosystem health. Developing these methods is a daunting task and leads some to reject this approach due to the difficulties involved.

The lack of consensus about whether or not to pursue the development of such an efficiency standard and how to approach its implementation framed the analysis in this report.

Context of Analysis

We performed this analysis at the request of the Statewide Water Planning Branch of the Department of Water Resources (DWR). DWR is required by statute to provide updates to the California Water Plan every five years, and is currently developing the next version of the update. The Update includes descriptions of “statewide water supplies, water uses, and actions that could be taken by water agencies to improve future water supply reliability.”¹ There have been requests that the next Update address the concept of efficiency for environmental water use, and DWR perceived the need to obtain an independent analysis of the topic given the state of contention among stakeholders about the concept.

DWR works with a statewide Public Advisory Committee that provides input to the preparation of the Water Plan Update. Advisory Committee membership “is intended to represent a diverse cross-section of water use and water management interests, with broad geographic distribution from throughout California.”² The state’s primary water interests make up the committee – including agricultural interests, state and federal agencies, environmental groups and urban water districts.³

Methodology

We began our analysis by developing a standard questionnaire that we used as the basis for interviews with targeted representative stakeholders.⁴ Questions focused on the stakeholders’ role in state water planning, their current understanding of the concept of WUE as applied to the environment, examples of inefficiency in environmental water use, and suggestions for how to facilitate the improvement of water use efficiency in the environmental sector. From a list of those interested in participating, we interviewed Advisory Committee members that represent the main sectors of water use planning. These interviews provided valuable information and perspectives that we have made use of in this report; however, we have refrained from citing specific conversations or people.⁵

We then conducted a literature review that aimed to investigate measures of efficiency currently used for environmental purposes that may help develop a concept of WUE for the environmental sector in California. This research included ecosystem performance indicators, ecosystem services valuation, urban and agricultural water use efficiency history and measures, legal and regulatory concerns, and other relevant topics.

Next, as subsequent sections of this report describe, we chose a term and developed a definition that address stakeholders’ interests and can serve as a starting point from which to further develop a more complex definition of efficiency. We also developed and evaluated alternative approaches to implement this concept. During the course of our analysis we recognized that these alternatives function more effectively as interrelated components of our definition of efficiency than as stand-alone alternatives from which water planners must choose.

¹ *About CALFED*. California Bay Delta Authority. 15 April 2004

<http://calwater.ca.gov/AboutCalfed/adobe_pdf/CALFED_Standard_Presentation_History_and_Context_3-18-04-2.pdf>.

² *About CALFED*. California Bay Delta Authority. 15 April 2004

<http://calwater.ca.gov/AboutCalfed/adobe_pdf/CALFED_Standard_Presentation_History_and_Context_3-18-04-2.pdf>.

³ See Appendix A for a list of the full Advisory Committee.

⁴ See Appendix B for the list of interview questions used.

⁵ See Bibliography for names of those interviewed.

Scope

Our analysis focused on two main issues: *whether* and *how* to assess the relative efficiency of water use for environmental purposes in California. Interviews with stakeholders and an evaluation of current water allocation practices led us to respond affirmatively to the first issue, and to further pursue the second. Therefore, this report develops the concept of WUE within the environmental sector, and introduces a term that all stakeholders can agree on to describe that concept. We also investigate potential implementation strategies for improving efficiency, as defined in this report. We aim to provide a starting point from which progress can be made on this issue, as well as provide suggestions on how to proceed.

Our analysis is directed strictly towards the environmental sector, and the goal of maximizing environmental benefits from a given amount of water dedicated to that sector. We do not address WUE in the agricultural or urban sectors, and our results are not intended to draw a comparison to those sectors. While we recognize that some stakeholders desire such inter-sector comparisons, environmental benefits are not sufficiently quantifiable (as discussed above) to allow these direct comparisons.

2.0 The Rationale for MEWUE

While WUE is being applied in urban and agricultural contexts, some stakeholders feel it is not a useful term or concept for environmental applications. In this section we forecast and assess the merits of the likely outcomes if the water planning community chooses to disregard this concept and continue current planning practices. In so doing, we briefly describe current decision-making practices for allocating water to the environment. We demonstrate why, in our view, current practice in the environmental sector highlights the need for a more explicit consideration of WUE and in fact is already moving in this direction in an ad hoc fashion.

We then present a term to address the concept of WUE with respect to the environment. We explain how this concept can benefit the environment and promote wise water use planning.

2.1 Present Trends in Management of Environmental Water

Description of Current Practice

Most current environmental water planning decisions are driven by regulatory compliance, not directly by efficiency or environmental benefits. An example of this phenomenon is the effort to meet the Delta salinity requirement in 2003, discussed as a case study below. In general, environmental regulation has provided and continues to provide valuable mechanisms for environmental improvement. However, many regulations themselves are created in response to a crisis and thus are tailored to that specific issue. This leads at times to an inappropriate focus on specific species or components of environmental quality. For example, state and federal endangered species legislation has been an effective mechanism for procuring water for the environment. This legislation motivates action on behalf of the listed species, which may or may not effectively address the needs of ecosystems as a whole.

Given a system of regulation and decision-making that is in large part reactive to crisis, science is often not as critical a component of environmental water use decisions as some desire. Policymakers are rarely in a position to make a considered evaluation of the tradeoffs involved with using water for alternative environmental applications. There is no office or organization serving as a clearinghouse for making comparative judgments of the benefits derived from various projects.

Many stakeholders stress the importance of adaptive management. Adaptive management is, generally, a practice of “learning by doing,” or of evaluating the performance of past successes and failures and applying the insights gained to future projects. While some organizations are practicing adaptive management, this approach is not being fully implemented on many projects. CALFED⁶ has recently issued an evaluation of its Ecosystem Restoration Program (ERP) that specifically lists improving the process of “learning by doing” as one of its key recommendations.⁷ No specific mechanism exists to mandate or encourage adaptive management across organizations. We discuss adaptive management further in this report, particularly in section 3.2.1.

Accountability for the satisfactory environmental performance of projects is currently established through policymakers’ scrutiny of dollars and quantities of water spent. Some stakeholders feel that this mechanism is an appropriately rigorous screen. Others feel that this level of accountability is insufficient and weaker than that established by WUE standards in the urban and agricultural sectors.

Many organizations involved with environmental water planning or ecosystem restoration in California are pursuing innovative, evaluative methods. For example, the Bay Institute has developed a Scorecard that grades the ecological condition of San Francisco Bay using eight different science-based indicators.⁸ The Nature Conservancy has developed Conservation by Design, a framework for selecting conservation goals and measuring the success of its efforts.⁹ We discuss additional examples as case studies in later sections of this report. Other organizations are recognizing a need for a more systematic approach to assessing the success of their efforts. CALFED’s recent evaluation of its ERP calls for greater efforts to evaluate the performance of projects.¹⁰

Case Study 1

The X2 Salinity Standard and the Strand of the 2003 Salmon Hatch

The Bay-Delta Accord (1994) and the resulting Water Quality Control Plan (1995) established the X2 standard to control the penetration of salt water into the Delta estuary. X2 sets a minimum distance, in kilometers, from the opening of the Golden Gate to the point at which the salinity of the Delta is two parts per thousand.^{11,12} In order to maintain X2 at various seasonal values, water planners must manage

⁶ CALFED is a consortium of 24 state and federal agencies whose mission is “to develop and implement a long-term comprehensive plan that will restore ecological health and improve water management for beneficial uses of the Bay-Delta System.” *About CALFED*. California Bay Delta Authority. 15 April 2004

<http://calwater.ca.gov/AboutCalfed/adobe_pdf/CALFED_Standard_Presentation_History_and_Context_3-18-04-2.pdf>.

⁷ *Ecosystem Restoration Program Project Evaluation Phase 2 Report*. CALFED Bay-Delta Program. 15 April 2004.

<http://calwater.ca.gov/Programs/EcosystemRestoration/ERPProjects_Phase2/Phase2_Report.pdf>.

⁸ The eight indicators track the Bay’s environment (habitat, freshwater inflow, water quality), its fish and wildlife (food web, shellfish, fish), management of its resources (stewardship), and its direct value to users (fishable/drinkable/swimmable). For more information about Scorecard, see *Ecological Scorecard - San Francisco Bay Index 2003*. The Bay Institute. 7 April 2004 <http://www.bay.org/Scorecard/Scorecard_report.pdf>. For more information on indicators generally, see Section 3.1.1.

⁹ The four steps in the Conservation by Design cycle are setting priorities, developing strategies, taking action, and measuring success. For more information, see *How We Work*. The Nature Conservancy. 7 April 2004.

<<http://nature.org/aboutus/howwework/about/>>.

¹⁰ *Ecosystem Restoration Program Project Evaluation Phase 2 Report*. CALFED Bay-Delta Program. 15 April 2004

<http://calwater.ca.gov/Programs/EcosystemRestoration/ERPProjects_Phase2/Phase2_Report.pdf>.

¹¹ *Case Studies, Part E: San Francisco Bay/Delta Estuary. Chapter E1: Background*. 15 April 2004

<<http://www.epa.gov/waterscience/316b/casestudy/che1.pdf>>

freshwater diversions upstream of the Delta to ensure that sufficient fresh water is available to flush the Delta. These seasonal distances are set to ensure the survival of several aquatic species, notably the delta smelt and longfin smelt.¹²

In 2003, unusually light winter precipitation created low flow conditions into the Delta. In response, the Bureau of Reclamation released 300,000 acre-feet of water from Folsom Dam on the American River in order to maintain X2 compliance. The high flow conditions on the American persisted for a few days until the extra releases were shut off. During the high-flow period, salmonids laid eggs high on the banks of the river. The subsequent flow reduction stranded these eggs on the riverbank.

These events destroyed much of the 2003 salmon spawn. Moreover, the early release from Folsom Dam meant that this water was not available later in the season, when it would otherwise have been released. These releases, in normal years, provide sufficient water to downstream users to allow the curtailment of pumping from the Delta while young salmonids are passing through on their way to the ocean. Due to the early Folsom Dam release, 300,000 fewer acre-feet of water were available in 2003 to supplant curtailed pumping, so the pumps were run more frequently during the salmonid migration. This further diminished the salmon population. The benefit gained by this series of events was maintaining the X2 standard and averting damage to the smelt and other Delta species.

Several stakeholders we spoke with saw this series of events as an example of inefficient use of environmental water. They felt that the harm caused by the strand of the salmon hatch and the loss of export curtailments outweighed the benefit to the Delta ecosystem gained by meeting the X2 requirement. They argue that there must have been a way to reallocate the available water to produce greater net environmental benefit. However, stakeholders did not agree on the source or explanation of this inefficiency, or on the characteristics of a superior solution. Some felt that the problem was the specific, inflexible standards set by the X2 regulation, and argued that the regulation itself led directly to inefficiency. The solution, in their minds, was to increase regulatory flexibility by allowing selective noncompliance with X2 when compliance would produce undesirable results such as these. Others viewed the situation as a product of bad management decisions, rather than inflexible regulation. They argue that a large short-term release from Folsom Dam was not the only or the best way to ensure compliance with X2, which is an important component of the health of the Delta. In their view, other management options may have existed¹³ that would have maintained X2 compliance while avoiding a significant impact on the salmonid population.

This case study illustrates a number of salient features of the current process of environmental water use decision-making. A short-term crisis and a regulation were central drivers of water allocation. The decision-making process did not directly involve scientific or economic analysis of the tradeoffs between different potential actions or the environmental benefits that would accrue in different scenarios. Agencies made an isolated decision based on a single criterion instead of addressing holistic ecosystem needs. The existing systems of management, according to some, were not sufficient to handle the issue optimally.

¹² *San Francisco Bay Freshwater Inflow Index: Indicator Analysis and Evaluation*. The Bay Institute. 15 April 2004 <http://www.bay.org/Scorecard/Freshwater_Inflow.pdf>.

¹³ For example, managers could have released water more slowly from Folsom Dam, or released water from other dams as well.

Discussion of Projected Outcomes if Current Trends Continue

Absent the introduction of a water use efficiency approach, we can expect the scene going forward to look much like what we have described above. Some stakeholders would be pleased with this outcome, and see no need for a new paradigm. Others would be disappointed, particularly those desiring greater accountability for the benefits achieved by dedicating water to the environment and those who wish for a better way to understand benefits of water use in the environmental sector. Water managers will continue to make decisions principally on the basis of issues other than direct maximization of environmental benefits, as discussed above. While some organizations are employing some form of adaptive management, there is no cross-organizational mechanism to ensure such practices.

It would be erroneous and dismissive to suggest that current ecosystem restoration practice is static and does not provide the potential for environmental water use to become more efficient. Indeed, many organizations are moving towards innovative processes that hold plenty of promise in further integrating science, adaptive management, and ecosystem performance indicators. Again, CALFED's ERP project evaluation is a good example, and specifically recommends increased use of these practices. So, even without formally implementing a WUE approach, we would expect progress towards efficient water use. Many stakeholders see these practices as distinct from an efficiency concept. However, we see these ideas as potential methods to implement WUE, as we will later discuss. The fact that different organizations are recommending similar measures for improving water use suggests a setting ripe for systemic improvement. Section 3 of this report discusses these methods and ideas for how they can be pursued more comprehensively.

2.2 The MEWUE Concept and Terminology

Agreement on a Central Concept

Though common perception is that there is much disagreement about WUE for the environment, all of the stakeholders that we interviewed for this project agree that water planning should try to *maximize the environmental benefits obtainable from a given amount of water that is dedicated to the environment*. This concept, in our opinion, is the foundation for defining WUE for the environmental sector. The obvious challenge is how to go about measuring or evaluating these benefits. We will discuss some potential methods to measure benefits in section 3 of this report, and we will make some recommendations about how to proceed. The method of evaluating benefits will be critical to some stakeholders' ultimate acceptance of the approach. However, providing consensus on a central concept and engendering acceptance of the need for WUE in the environment will set the basis for a more responsive discussion about how to measure benefits. Therefore, we first seek to attach a term to this concept that best captures what it is trying to accomplish. We propose Managed Environmental Water Use Efficiency (MEWUE).

MEWUE: a mechanism to analyze alternative uses of managed environmental water to determine which allocation of a given amount of water will maximize environmental benefits, and a means to improve decision-making over time.

Discussion of MEWUE as the Chosen Term

The initial term proposed by those considering this concept was Environmental WUE. Subsequently, others proposed Ecosystem Restoration WUE as a potentially superior term. In addition, some suggested *effectiveness* in place of *efficiency*. Different parties we spoke with had concerns with each of these

terms. We considered the relative merits of alternative terms and found that MEWUE works the best to capture the ideas on which stakeholders agreed.

The benefit of using the term Environmental WUE is that it is a comprehensive descriptor and clearly represents the third major sector of water use. However, this term can be interpreted to mean that the goal of implementing WUE is to evaluate the returns on the environment's use of water in its natural state. The true goal of WUE with regard to the environment, as expressed by stakeholders and the Department of Water Resources (DWR), is to evaluate the returns on water specifically devoted to the environment by *humans*.

Ecosystem Restoration WUE successfully narrows the issue to how humans use water for ecosystem restoration. However, this term may be overly specific and would leave out activities our concept is intended to encompass, such as ecosystem maintenance. Furthermore, some feel the term implies that there is a goal to restore ecosystems to a pre-existing and unspecified state, and are uncomfortable with this connotation.

We propose the term “Managed Environmental WUE” as a way to resolve the concerns described above. The term “Managed” excludes the possibility of evaluating the returns of water in its natural state, clarifying that only waters subject to human management are being considered. Including “Environmental” rather than “Ecosystem Restoration” allows a broader application of the term to include other activities as well as restoration.

Another issue that arose from our discussions with stakeholders on terminology and from materials written by stakeholders was whether the measurement, the “E” in WUE, should be *effectiveness* or *efficiency*. As commonly used, *effectiveness* refers to the amount of benefit obtained from water. *Efficiency* is the benefit, or *effectiveness*, per some unit of water.

The word *effectiveness* implies improvement. In other words, an action was effective if it made a change for the better. Therefore, Water Use Effectiveness would seem to measure whether a specific application of water is able to bring about ecosystem improvement. This word does not necessitate a measurement of the amount of water used. Because *effectiveness* does not require a measurement of the water used to obtain a benefit, it does not allow water planners to readily evaluate which application of water would be most beneficial given a specific amount of water. While *effectiveness* is preferred by some for its lack of parallelism to other sectors, not having a basis for comparison of competing uses (amount of water) weakens its use within the environmental sector as well.

The term *efficiency* has a more direct parallel with urban and agricultural WUE, which for some is positive, while for others is not. Some feel that *efficiency* implies a more rigorous measure that would allow for water in the environment to be evaluated in a similar manner as water in other sectors. Others are concerned that an efficiency measure requires a simplicity of analysis that is impossible or scientifically unsupportable, and might focus on micro-level indicators that do not accurately capture the complexities of ecosystem performance.

The issue of comparison is highly important to improving the way environmental water is used. If there were an infinite amount of water, there would be no need to compare the benefits of providing water among different uses. Unfortunately, as our readers are well aware, there will always be competing needs

for water in California, both between sectors and within each sector. Given a limited amount of water, it is important to figure out which uses will provide the *greatest* environmental benefit. Without an effective measure of how much benefit is gained under each option *for that amount of water*, resources could be misallocated.

There may be times when an additional amount of water will greatly improve the ecosystem in one region, but only mildly improve another. It is even possible that too much water in a specific region could cause harm to that area and should be reallocated to an area in need. For this, understanding incremental improvements based on amounts of water will be necessary.

Therefore, we recommend that MEWUE be a measure of efficiency, not effectiveness. *Efficiency* includes a basis for comparison within environmental uses, which better describes the necessary concept. The definition of *efficiency* we are offering does not imply anything specific about how to measure benefits, nor does it suggest that they will be easily quantifiable. It does not necessarily suggest the existence of a single linear, numerical metric. Using the word *efficiency* is necessary to capture the idea that we want to evaluate benefits per unit of input, rather than simply the total benefit of a project independent of inputs.

The Case for Applying the MEWUE Concept

Many people are uncomfortable with the idea of having to measure environmental benefits, feeling that these benefits are inherently unquantifiable, or are so difficult to quantify that the exercise is best not pursued. It is obviously a difficult task to try to create a comprehensive calculation of the benefits the environment gains from water use. However, planners find themselves making these measurements implicitly all the time. Given competing water needs, there is no way to avoid them. Any time a decision is made to allocate water to one environmental project above another, the decision-maker is making a judgment that the first project creates greater benefit. Right now, those considerations can include political ease of decision, existing legal restrictions, and an understanding of ecosystem needs. MEWUE would be used to improve the information available for the decisions that are already being made. MEWUE would not create a new set of questions; rather, it would inform those questions that are already being asked.

It is hard to allay the fears that some have of incorrectly measuring environmental benefits. However, it is even more difficult to claim that decisions made based on implicit measures and beliefs are better for the environment than those made with broad involvement and based on some imperfect but explicit consideration of environmental benefits.

In addition, without a way to evaluate efficiency, it is difficult for water planners to learn from mistakes. It is necessary to implement a type of measure or process that would allow for a more systematic review of what types of water allocation are most beneficial for the environment. Even if the measure is imperfect, which any measure would certainly be, an effective process of implementing it will enable assessment of and improvement on its flaws. While the water planning community should take all possible steps to develop a correct and comprehensive measure, even an imperfect measure will provide a starting point for improving environmental water use. Without a measure, correct or incorrect decisions can be made, but little evaluation can follow.

The complex nature of the environment requires a comprehensive system to improve the efficiency of how water should be allocated to it. Multiple measurements will likely be necessary to understand environmental efficiency, and these measurements will likely require continual updating and revision. This should not be disheartening. Just as the Department of Water Resources dedicates an Office to understanding and improving urban and agricultural WUE, MEWUE will necessitate ongoing effort. We discuss the potential dimensions of this effort in Section 3.

Summary

MEWUE is a term intended to address the concerns of all parties discussing water use efficiency with respect to the environment. It is intended to be a starting point from which people can begin to assess the various ways to measure environmental benefits.

In this section, we have discussed the consensus concept MEWUE is designed to address (maximizing the benefit of given amounts of water dedicated to the environment by human decisions) and why it is important to consider that concept. We have not yet addressed the thorny question of how to implement a measure of the environmental benefits MEWUE would seek to maximize. Some potential approaches will be outlined in the remainder of this report. However, an understanding of how to improve efficiency will take time to evolve. Therefore, we feel that explaining the term and agreeing on its basic meaning are essential to maintaining the motivation to support the idea of improving MEWUE.

3.0 Potential Methods for Implementing MEWUE

3.1 Technical Methods

3.1.1 Ecological Indicators

Description

An ecological indicator is a “measurable feature or features that provides managerially and scientifically useful evidence of environmental and ecosystem quality or reliable evidence of trends in quality.”¹⁴ Ecological indicators, as used in this report, refer to both biological indicators of water quality (bioassessment) and physical indicators of habitat suitability. There are variants of both assessment systems in use today in the United States and throughout the world. The most widespread use of biological indicators is in water quality monitoring. Currently, all 50 states, several tribes and territories, and several other countries have some level of bioassessment procedures in place for monitoring water quality, as well as investigating specific impairment or pollution events. Habitat quality assessment is also in wide use, although these protocols are less well-developed and standardized, probably due to the existence of fewer regulatory drivers.

The theory of bioassessment is based on the close relationship between the abundance and diversity of species (primarily benthic macroinvertebrates, algae, and fish) with known water quality tolerances and the quality of that water. Bioassessments are potentially very sensitive to a variety of aspects of water and habitat quality. Additional habitat quality indicators include assessments of channel dimensions, channel gradient, channel substrate size and type, habitat complexity and cover, riparian vegetation cover

¹⁴ *Water Quality Indicators*. State Water Resources Control Board. 12 April 2004
<<http://www.swrcb.ca.gov/swamp/wqindicators.html>>.

and structure, anthropogenic alterations, and channel-riparian interaction.¹⁵ These indicators may be used to assess the habitat suitability for species of concern, as well as overall ecological health.

Case Study 2

Florida Uses Bioassessment to Target and Evaluate Restoration and Mitigation Projects¹⁶

The Florida State Department of Environmental Protection (DEP) uses bioassessment in monitoring of specific water bodies of concern, and has also used bioassessment in several cases to measure the effectiveness of specific management actions. For example, the DEP measured the conditions on Canoe Creek in northern Escambia County, before and after paving the upstream clay-bed Bratt Road. The 1997 assessment reported low ecological indicator index scores. The hypothesized cause of these low scores was sediment impacts from the unpaved road, which prompted mitigation measures. The 2002 assessment, after the road was paved, found an increase of 76%, 83%, and 59% in the three indices used, to between 160% and 210% of “threshold significance” levels.

Using ecological indicators allows DEP to target resources to greatest need, evaluate success of projects, and learn from experience.

Case Study 3

Clean Water Act Water Quality Monitoring Increasingly Utilizing Ecological Indicators

Water Quality Standards (WQS) under the Clean Water Act (CWA) consist of three elements: designated use, narrative and numeric criteria adopted to protect the use, and policies to prevent degradation. Ecological indicators are increasingly being used in monitoring to assess whether a waterbody meets its WQS, in reporting this status and in implementing mitigation and restoration measures.

Some states, such as Oregon, Ohio, Florida, Maryland, Kentucky, and Maine, have already constructed biological assessment and standards programs for streams and small rivers, and are managing their CWA programs at least partially through numeric or narrative ecological indicators. Most other states are developing programs and are at various levels of implementation.¹⁷ The U.S. Environmental Protection Agency (EPA) has recently instituted the Consolidated Assessment and Listing Methodology (CALM) to track, publicize, and facilitate states’ CWA bioassessment programs, a function exemplary of the benchmarking described in section 3.2.1.¹⁸

The development of protocols and regulatory structure for the use of ecological indicators across the country provides multiple models and guides for their use in MEWUE assessment, both from a technical and a bureaucratic viewpoint. Adapting the model, not to mention the protocols and the data, of CWA bioassessment could yield significant cost efficiencies in ecological indicator development.

¹⁵ Barbour, Michael, Jeroen Gerritsen, Blaine D. Snyder and James B. Stribling. “Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition.” *EPA 841-B-99-002*. United States Environmental Protection Agency; Office of Water; Washington, D.C. (1999)

¹⁶ *Bioassessment Ecosummaries of All Districts*. Florida Department of Environmental Protection. 15 April 2004 <http://tlhdwf2.dep.state.fl.us/eswizard/eco_results.asp>.

¹⁷ *Summary of Biological Assessment Programs and Biocriteria Development for States, Tribes, Territories, and Interstate Commissions: Streams and Wadeable Rivers*. EPA-822-R-02-048. United States Environmental Protection Agency. (2002)

¹⁸ *Consolidated Assessment and Listing Methodology – Toward a Compendium of Best Practices*. United States Environmental Protection Agency. 12 April 2004 <<http://www.epa.gov/owow/monitoring/calm.html>>.

California Has Several Ecological Indicators Currently in Use

In California, ecological indicators of several different types are already used by DWR, the Department of Fish and Game, the State Water Resources Control Board, the Regional Water Quality Control Boards, the Department of Parks and Recreation, several municipalities including San Jose and San Diego, and several Native American tribes. Universities (UC Davis, Berkeley, and Los Angeles) and watershed citizen groups have also developed or used ecological indicator assessment. Two of the most developed methods are described in the following table.

Table 1

| Indicator | Description and Current Use | Potential Applicability to MEWUE |
|---|---|---|
| California Stream Bioassessment Procedure (CSBP): ¹⁹ | The CSBP is a regional adaptation of the national Rapid Bioassessment Protocols outlined by EPA. The CSBP has been further refined by the Department of Fish and Game's Aquatic Bioassessment Laboratory to be relevant to California's ecoregions. | CSBP may be applicable in monitoring watershed health, assessing the efficacy and efficiency of specific restoration projects, or in targeting proposed projects. |
| California Monitoring and Assessment Protocol (CMAP): ²⁰ | CMAP is the California-specific evolution of EPA's Environmental Monitoring and Assessment Protocol ²¹ which assesses water quality. CMAP uses random, statistical selection of samples from a selection of reference and impacted sites to create a cost-effective monitoring system of trends. | CMAP may be applicable in monitoring the efficiency of water management alternatives across regions and over time. |

Applicability to MEWUE

The use of indicators to measure the ecological benefits of managed environmental water use is feasible and appropriate. Myriad methods of ecological assessment that show significant scientific reliability have been and continue to be developed, including several in California. Indicators could be used to monitor ecological quality, to aid in deciding between projects, and to assess the effectiveness of completed projects and programs.

Selection of sufficient and appropriate indicators for assessing MEWUE is critical. A multimetric approach that captures the range of values for which it is important to manage is preferable to a simple measure such as single species populations. Ecological indicator selection should be accessible to broad stakeholder involvement, and not restricted to scientists and agency personnel.

Because bioassessments must be calibrated to reference “unimpaired” conditions, they are necessarily region-specific. The applicable scale of individual indices may range from the watershed to the

¹⁹ *California Stream Bioassessment Procedure Protocol Brief*. Aquatic Bioassessment Laboratory, California Department of Fish and Game. 26 March 2004 <http://www.dfg.ca.gov/cabw/csbp_2003.pdf>.

²⁰ *California Monitoring and Assessment Program*. Aquatic Bioassessment Laboratory, California Department of Fish and Game. 30 March 2004 <<http://www.dfg.ca.gov/cabw/Field/cmap.html>>.

²¹ *Environmental Monitoring and Assessment Program*. United States Environmental Protection Agency. 30 March 2004 <<http://www.epa.gov/emap/index.html>>.

ecoregion.²² Additional factors relevant to the selection of appropriate indicator protocols for MEWUE include the cost of collecting and analyzing samples and the level of precision desired by decision makers.

3.1.2 Instream Flow Requirements

Description

The term “instream flow requirements” refers to the quantity and schedule of water required to protect the structure and function of aquatic ecosystems at some specified level of ecological health. While methods for directly measuring ecological health are still evolving, there are currently several techniques available that can provide such measurements in comparison to a reference condition, such as natural flow. One such technique is the Instream Flow Incremental Methodology (IFIM),²³ a tool used nationwide that is accepted by most resource managers as the best available method for determining the relationship between flows and aquatic habitats.²⁴ This methodology aims to assess the ecological effect of incremental changes in stream flow through the following five steps:²⁵

- Problem Identification – Conduct physical analysis to define the affected physical location, and the aquatic resources of most concern. Perform legal-institutional analysis to identify interested parties and their objectives, and provide a better understanding of the impacts of the proposed project.
- Study Planning – Outline necessary data collection and require that all interested parties agree to a baseline hydrologic time series that will act as the reference condition.
- Study Implementation – Select sampling locations and collect data outlined in the Study Planning step, and use the results and predictive model (e.g. PHABSIM – physical habitat simulation) to estimate the relation between flow and total habitat.
- Alternatives Analysis – Compare alternative water uses against these instream flow requirements to determine the potential impacts of a proposed water project, and identify the habitat costs and benefits of the project.
- Problem Resolution – Reconvene interested parties to make a decision based on the results.

Collaboration among stakeholders is an important component of this process, as varying interests should agree on ecological health goals. Once instream flow requirements are set, environmental water allocation decisions can be guided by the relative ecological health improvements that result from application of a given amount of water. For example, if several areas are competing for water, planners could look at how well current allocations are meeting instream flow requirements in those areas. They could then make a decision based on which area(s) would achieve the greatest benefit relative to their targeted ecological health goals, thereby increasing the efficiency of managed environmental water.

²² An ecoregion is an area of the country with similar geography, climate, and biology. There are considered to be 13 “Level III” ecoregions in California, according to EPA.

²³ “Instream Flow Incremental Methodology (IFIM).” Fort Collins Science Center. 10 April 2004
<<http://www.fort.usgs.gov/products/software/ifim/ifim.asp>>.

²⁴ “Instream Flows in Washington State of Washington: Past, Present and Future.” Washington Department of Ecology. 10 April 2004
<<http://www.olympus.net/community/dungenesswc/InstreamFlowversion12.PDF>>.

²⁵ “Instream Flows in Washington State of Washington: Past, Present and Future.” Washington Department of Ecology. 10 April 2004
<<http://www.olympus.net/community/dungenesswc/InstreamFlowversion12.PDF>>.

While uncertainty is present in this process, it can be reduced through careful study design, full inclusion of multiple viewpoints, and selection of an appropriate scale. Also, the accuracy of water project decisions can be evaluated and revised through post-project monitoring and analysis. In this way, adaptive management can reduce uncertainty and improve assessment and management of future projects.

Case Study 4

Washington State's Use of Instream Flows²⁶

Washington State first introduced a systematic approach to instream flow protection in 1967. The legislation was updated with the Water Resources Act of 1971, which states the goals of water allocation in Washington as follows: "Allocation of water among potential uses and users shall be based generally on the securing of the maximum net benefits for the people of the state. Maximum net benefits shall constitute total benefits less costs including opportunities lost." As stated in section 2.2 of this report, this concept of maximizing net benefits is consistent with views expressed by stakeholders in California.

The process for setting flows in Washington is a collaborative effort led by the Department of Ecology, the state's principal environmental management agency. The department has authority to set flows only after going through public processes to ensure that issues are identified and considered. This gives local citizens, local government, state agencies, and tribes an avenue for involvement in establishing or amending instream flows. Flow recommendations must have unanimous support of all government members and tribes and a majority of non-government members. The technical process of setting flows utilizes IFIM and PHABSIM and takes multiple factors into account when setting flows, including fish, water quality, climate, dams, cultural values, and recreation, among other things. Using this information, the tools predict how the quantity of available fish habitat changes in response to incremental changes in flow.

The use of instream flow requirements in Washington has been influential in establishing management goals and maintaining sufficient levels of aquatic health. While controversy surrounded the initial setting of flows, the more collaborative approach that is now in place has acted to increase stakeholder satisfaction with the process. If California decided to pursue this approach, the state could benefit from Washington's experiences, particularly regarding the collaborative process and the scientific techniques employed.

Applicability to MEWUE

This method provides an eco-centric approach to managed environmental water use efficiency. It attempts to determine the water needs of an ecosystem to protect fish and other environmental values, and to make management decisions based on this science. If implemented, a collaborative process²⁷ like the one employed in Washington State allows stakeholders to provide input in setting or amending instream flow requirements and can thus increase stakeholder satisfaction. In addition, the process is quite amenable to adaptive management, as post-project assessment allows for a substantive evaluation of the accuracy of predicted instream flow requirements, which can subsequently be updated. This approach can also reduce uncertainty, as future modeling can be revised based on these post-project analyses. Technical feasibility is another strength of this technique, as widely accepted technology (IFIM) is

²⁶ "Instream Flows in Washington State of Washington: Past, Present and Future."
Washington Department of Ecology. 10 April 2004
<<http://www.olympus.net/community/dungenesswc/InstreamFlowversion12.PDF>>.

²⁷ We discuss the importance of collaboration in more detail in Section 3.2.2.

available to develop instream flow requirements based on a baseline hydrologic time series. The technical viability of this method is also supported by successful implementations in other countries (such as South Africa)²⁸ and states, including Washington.

This technique improves efficiency of environmental water use by ensuring that management decisions are made in the context of approaching an accepted “goal” condition. The extent to which managed flows achieve this goal is a measure, albeit rough and unquantified, of benefits. Stakeholders interested in achieving a single metric of efficiency may not be satisfied. Furthermore, several factors prohibit this method from guaranteeing a single, best solution. Ecological complexity makes it impossible to fully assess and model the health of a given ecosystem, which leads to imperfection and uncertainty in the data and models. In addition, rational people may disagree, even on a science-based process, and so the collaborative process is not guaranteed to produce consensus. Still, the process would strengthen the scientific basis for environmental water allocation decisions.

3.1.3 Economic Valuation

Description

Economic valuation of ecological services and environmental quality is a rapidly developing field and is increasingly being used in natural resource management. Theoretically, accurate economic valuation of the benefits of alternative environmental water uses could be used to calculate the relative efficiency of these actions.

The purpose of any economic valuation is to estimate the value that consumers place on goods and services. When those goods and services are traded in a well-functioning market, their value can be assumed to equal their price. When, like environmental values, these goods and services are not traded in a market, their value must be deduced through “non-market valuation” techniques. There are a variety of such techniques that have been developed to estimate the public’s value for environmental goods and services.²⁹ Because of the large number of people affected, the sum of the value citizens place on environmental amenities can be quite large.

Economic valuation is already used to some extent by government agencies in cost-benefit analysis of water management alternatives, including water storage development, conservation measures, and specific restoration projects. It is also used in environmental damage assessment. Most non-market economic valuation is being conducted in the academic context.

²⁸ “Environmental Flow Assessments for Rivers: Manual for the Building Block Methodology.” 7 April 2004
<<http://www.fwr.org/wrcsa/tt13100.htm>>.

²⁹ See Appendix C for more details.

Case Study 5**South Platte River Conservation and Restoration Valuation Study**³⁰

Loomis et al. studied local residents' value for restoring certain ecosystem services along a 45-mile stretch of the ecologically important yet highly impacted South Platte River in Northern Colorado. One hundred residents participated in an in-depth valuation survey that elicited yes-or-no reactions to randomly-generated "proposed" water fees, which were analyzed to arrive at respondents' average "willingness to pay" regarding purchasing increased ecosystem services.

The study involved extensive respondent education in current resources and land use, proposed restoration and mitigation activities, and expected environmental benefits. These benefits would be achieved through specific management actions including purchasing a ten-mile-wide conservation easement along 45 miles of the river, creating buffer strips where cropland and cattle grazing would be eliminated and native vegetation would be planted, and buying water rights to increase stream flows by 50% to 70%. The ecosystem services residents were asked to value included dilution of wastewater, natural purification of water, erosion control, habitat for fish and wildlife, and recreation.

A mean annual household willingness to pay of \$252 was estimated for the increase in ecosystem services on the 45-mile stretch of the river. This value, summed across the area's population, establishes an estimated value to the public of performing the actions of at least \$19 million, compared to an estimated cost of the proposed actions of \$13.5 million. Although no tax or charge resulted from the study, this estimated value has supported the conservation work of the Fish and Wildlife Service and Centennial Land Trust.³¹

Applicability to MEWUE

Economic valuation may be useful *as a component* in estimation and quantification of environmental benefits to aid in MEWUE assessment. A study such as the South Platte study could be conducted before a project or management decision to gauge the public's value of the environmental benefits, or after a change to determine the value achieved. With additional development, such a study could be used to inform decision-making on proposed projects, to assess relative efficiency of alternative programs or projects, and to evaluate success of existing programs.

Economic valuation would probably be most useful as a measurement of long-term, regional-scale, aggregate benefits of environmental water allocations. For instance, an economic valuation of CALFED ecosystem restoration activities is a feasible use of this technique. Economic valuation may also be most useful as a component of ex ante assessment of restoration alternatives. Depending on the quality and comprehensiveness of the analysis, comparative valuation of ecosystem benefits between projects may be an important contribution to decision making.

However, economic valuation cannot stand as a sole quantitative assessment of environmental benefits. Valuation techniques still only measure a portion of value that may be attributed to environmental

³⁰ Loomis, John, Paula Kent, Liz Strange, Kurt Fausch and Alan Covich. "Measuring the Total Economic Value of Restoring Ecosystem Services In an Impaired River Basin: Results From a Contingent Valuation Survey." *Ecological Economics* 33 (2000): 103–117.

³¹ *Partners for Fish and Wildlife Program, South Platte River Focus Area*. US Fish and Wildlife Service. 30 April 2004 <<http://coloradopartners.fws.gov/co31.htm>>.

resources.³² To the extent that important environmental values are missing, economic valuation may not be an appropriate tool for seeking to maximize environmental benefit.

Given the range of services to be valued and the immaturity of the methods, economic valuation continues to be highly controversial. It is often questioned by those that find the methods and values unreliable and by those that feel it is immoral or impossible to value the natural world. For these reasons, economic valuation continues to have limited support in some sectors, including public opinion.

3.2 Institutional Methods

3.2.1 Benchmarking and Best Management Practices

Description - Benchmarking

Benchmarking is the process of monitoring the performance of management practices and restoration projects and identifying the most efficient among them for possible adaptation and implementation elsewhere. Benchmarking establishes performance standards that other managers or projects seek to emulate. The process of benchmarking moves an industry overall toward greater efficiency over time.

Benchmarking has two parts: the harvesting of benchmarks from existing projects and the application of these standards to future projects. In the harvesting step, assessing the success of projects and identifying best practices requires some process of systematic assessment and some measure of success. Benchmarks may be tolerant of some uncertainty in the measurement of benefits and could be implemented with relatively loose quantitative or even qualitative measures. Benchmarks might be based on ecological indicators, or on more subjective criteria, such as the success of projects in meeting pre-project objectives.

With a centralized agency monitoring the success of projects or programs across agencies and districts, benchmarks can be identified and publicized, allowing future projects or management decisions to adapt and apply successful models. Benchmarking is also accomplished by project sponsors being responsible for post-project auditing of water management regimes and restoration projects and publicizing exceptional results. This serves the dual purpose of harvesting benchmarks of success and providing some degree of accountability for success.

An ongoing benchmarking process would institutionalize adaptive planning. Projects would be explicitly studied for successful and unsuccessful components, which would then be incorporated or avoided, respectively, in future projects. Benchmarking can be conducted on a comprehensive basis across programs, as an added audit requirement on individual projects, or both. A benchmark program may be implemented by individual managers, or it may be undertaken by a centralized agency.

Benchmarking the efforts of California's water managers to measure and improve MEWUE would increase the rate of diffusion, adoption, and innovation of successful practices and over time increase efficiency. Benchmarking may also lead to the identification of Best Management Practices.

³² For instance, valuation techniques will only capture anthropogenic value. That is, they do not express any intrinsic value of nature, but rather reflect the values humans ascribe to nature.

Description - Best Management Practices (BMPs)

Best Management Practices are practices or policies that have consistently provided examples of successful performance and have been demonstrated to be cost-effective when implemented on a wide basis. BMPs reduce information costs to individual water managers and are by design robust in the face of uncertainty. BMPs represent “no regrets” actions, actions that have a high likelihood of being successful, regardless of uncertainties as to the magnitude of the effect. BMPs provide off-the-shelf solutions to improving efficiency, and so reduce information costs to individual water managers.

BMPs are well established in the agricultural and urban sectors. Effective Water Management Practices (EWMPs) in the agricultural sector have helped drive significant gains in efficiencies in this sector. Similarly, urban water suppliers have adopted BMPs requiring the implementation of 14 specific management programs or practices, as discussed in the case study below.

Case Study 6**California Urban Water Conservation Council Best Management Practices³³**

In 1991, more than 100 urban water suppliers committed to implementing long-term conservation measures called Best Management Practices, or BMPs, by signing the Memorandum of Understanding Regarding Urban Water Conservation (MOU). Today, more than 310 urban water suppliers, public advocacy organizations, and other interested parties have signed the MOU, forming a coalition known as the California Urban Water Conservation Council (CUWCC). These signatories have voluntarily committed to implementing 14 BMPs, including surveys of users’ baseline consumption and practices, audits of waste and leaks, implementation of specific conservation technologies, and conservation pricing.

The development of urban WUE BMPs allows water managers some certainty in the cost-effectiveness and benefits of proposed actions. Furthermore, the CUWCC process demonstrates a process for developing statewide, stakeholder-based agreement on BMPs.

Applicability to MEWUE

The evaluation of managed environmental water use efficiency is of little value without a process for deriving lessons from the process to be applied to future projects and management regimes. BMPs in a MEWUE context would be restoration projects, technologies, or management programs that have proven to be cost-effective in increasing efficiency of managed environmental water use. Examples of possible MEWUE BMPs include fish screens on water supply intake facilities and restoration techniques developed for the California Salmonid Stream Habitat Restoration Manual.³⁴

BMPs have potential to be successful in cost-effectively increasing WUE for managed environmental water, just as they have done for agricultural or urban WUE. MEWUE BMPs must be carefully developed to ensure effectiveness and must be adaptable over time.

³³ *California Urban Water Conservation Council About Us*. California Urban Water Conservation Council. 30 April 2004. <<http://www.cuwcc.org/aboutus.html>>.

³⁴ Flosi, Gary, Scott Downie, James Hopelain, Michael Bird, Robert Coey, and Barry Collins. *California Department of Fish and Game, California Salmonid Stream Habitat Restoration Manual*. 1998. 3rd edition. <<http://www.dfg.ca.gov/nafwb/manual.html>>.

3.2.2 Improved Water Management and Collaboration

Description

Several stakeholders mentioned that a lack of effective communication mechanisms and regulatory inflexibility often stand in the way of effective decision-making. Many argue that this lack of communication has led to inefficiencies in water management. For example, several stakeholders suggest that this lack of communication led to the inefficient use of water in the 2003 Folsom Dam release that we reference as a case study in Section 2.1. As we mentioned, that process did not involve a discussion of the tradeoffs between different potential actions. Making this decision within a framework of collaborative decision-making may have helped mitigate the negative results.

This section suggests the need for a new or enhanced mechanism for communication and decision-making that more effectively addresses ecosystem needs. The goal would be to create a collaborative process that would allow for a more flexible response to situations like the Folsom Dam release. Such an approach requires a commitment to understanding the interrelation of various goals within water planning.

Incorporating this approach would involve choosing from a range of options – from increased reliance on existing collaborative communication structures to replication of those systems that work well in some areas into other water planning situations. One possible outcome could take the form of a more formal communications structure, such as the case study discussed below. Another option might incorporate collaboration into decision-making processes that currently occur at various water planning levels (districts, etc.). The actual form that collaboration would take will vary across settings and requires an evaluation of current planning processes to determine where gaps in communication exist. The most important aspect of this approach is establishing a framework within which multiple stakeholders with diverse interests can identify areas of conflict and commonality.

Case Study 7

CALFED Operations Group (CALFED Ops)

The agreement to establish CALFED in 1994 “ended decades of infighting and regulatory uncertainty.”³⁵ Multiple agencies with a stake in Bay-Delta water planning created CALFED to address a lack of agency communication and deadlocked interests. CALFED, a collaborative resource program, was created with the mission to “develop and implement a long-term comprehensive plan that will restore ecological health and improve water management for beneficial uses of the Bay-Delta.”³⁶ CALFED makes real-time management decisions through an interagency group known as CALFED Ops. The fundamental notion of CALFED Ops is that agencies can best meet their individual responsibilities by sharing information.

CALFED Ops functions as a resource for all agencies involved in water planning in the Bay-Delta.³⁷ The idea behind the Ops group was that “information on fisheries, and water quality and flows, could be evaluated quickly using the distributed intelligence of the diverse agency and stakeholder members.”³⁸

³⁵ *About CALFED*. California Bay Delta Authority. 15 April 2004

<http://calwater.ca.gov/AboutCalfed/adobe_pdf/CALFED_Standard_Presentation_History_and_Context_3-18-04-2.pdf>.

³⁶ *About CALFED*. California Bay Delta Authority. 15 April 2004

<http://calwater.ca.gov/AboutCalfed/adobe_pdf/CALFED_Standard_Presentation_History_and_Context_3-18-04-2.pdf>.

³⁷ Participating agencies include DWR, Bureau of Reclamation, NMFS, USF&WS, EPA, DF&G and SWRCB.

³⁸ Connick, S. and Judith Innes. *Outcome of Collaborative Water Policy Making: Applying Complexity Thinking to Evaluation*. University of California at Berkeley, Institute of Urban & Regional Development. 16 April 2004 <<http://www-iur.d.berkeley.edu/pub/WP-2001-08.PDF>>.

CALFED Ops works to identify the interrelation of the goals of its subcommittee members³⁹ to detect potential conflicts and identify actions that will promote the goals of multiple subcommittees.⁴⁰ This process helps project planners determine the potential impacts of the activities they are pursuing, and CALFED Ops creates the communication and coordination mechanism within which consensus-based decisions can be made. CALFED Ops holds monthly meetings to make decisions and discuss potential changes and strategies. Decisions can involve changes in export rates, barrier operations, and reservoir releases. Ops group deliberations are conducted in consultation with water user, environmental, and fishery representatives.

On a host of outcomes by which to evaluate collaborative decision making, CALFED Ops scores highly. These measures include increased social and political capital, agreed-on information and shared understanding, end to stalemate, high quality agreements, innovation, and institutions and practices that involve flexibility.⁴¹ For example, the Ops group played a critical role in November and December of 1999, when “dry conditions, in combination with record high tides and the onset of a salmon out-migration produced a very complex and difficult water management situation.”⁴² CALFED Ops work groups held almost daily consultations during the five weeks these conditions prevailed, and “decision making was quick and effective, occurred at the lowest levels possible and the process provided a much more nuanced response than a single bureaucratic agency could provide.”⁴³

What stands out about how decisions were made in November and December of 1999 is that “unlike the way decisions were made prior to CALFED, the regulatory agencies were all involved in the decision-making, along with the resource managers and stakeholders.”⁴⁴ “A particularly extraordinary aspect of this innovation [CALFED Ops] was that stakeholders representing typically opposing viewpoints were able to come to agreement.”⁴⁵ In this case, resource managers faced different regulatory requirements that conflicted with each other. In the end, despite the fact that not all stakeholders were pleased with all outcomes, they all believed in the process of reaching decisions together.

Applicability to MEWUE

This approach to MEWUE would aim to improve communication by introducing a collaborative decision-making approach that explicitly aims to reduce conflicts and to support multiple goals of water planning interests. Water planners are likely to improve the efficiency of environmental water use within an improved decision-making structure. Currently, conflicts between various regulatory requirements and lack of a comprehensive water management structure for day-to-day communication and management may create inefficiency in the application of environmental water. Once a collaborative process is underway, it could potentially serve as a way to identify regulations that perhaps need changing or system-wide review among federal, state, and local water managers.

³⁹ Subcommittees include: Delta Levee habitat, drinking water, ecosystem restoration, environmental justice, water use efficiency, watershed, water supply and working landscapes.

⁴⁰ *Interrelation of CALFED Subcommittee Goals from the Ecosystem Restoration Subcommittee Perspective*. California Bay Delta Authority. 15 April 2004

<http://calwater.ca.gov/BDPAC/Subcommittees/EcosystemRestoration/ERP_Interrelation_Matrix_10-20-03.pdf>.

⁴¹ Connick & Innes (2001)

⁴² Connick & Innes (2001)

⁴³ Connick & Innes (2001)

⁴⁴ Connick & Innes (2001)

⁴⁵ Connick & Innes (2001)

This approach does not establish a mechanism with which to measure these improvements. Still, guidelines do exist for developing performance measurements using criteria such as an increase in high quality agreements, an end to stalemate, etc.⁴⁶

If instituted in a more formal manner, this method may take some time to yield results. The development of CALFED was a multi-year effort that required commitment from many stakeholders to work through the process. However, given that there is an existing framework from which to model future communication structures, it is possible that planners would see preliminary results reasonably quickly.

Implementing this method could involve some technical or legal difficulties to the extent that it suggests the need for changes in institutional structure or behavior or changes in regulation. However, the main thrust of this suggested approach is increasing communication and developing consensus-based decisions around current regulatory requirements, which in and of itself is not likely to involve technical or legal difficulty. Should future legislative action be determined necessary, a framework will exist within which to advocate for proposed legal changes. This method does not directly encourage adaptive management, but enhanced communication could potentially create a more flexible, adaptive decision-making context.

4.0 Conclusions and Recommendations

Coming To Terms with MEWUE

The scarcity of water in California necessitates the efficient use of any given quantity. Despite perceived disagreement about WUE for the environment, there is consensus among the stakeholders with whom we spoke that environmental water management should strive to achieve the greatest amount of benefit possible from the water made available. This key concept can provide the foundation for developing and implementing MEWUE.

Terminology being as important as it is, a large part of our task has been to develop a term to accurately describe what the concept encompasses and what it doesn't. We propose the term Managed Environmental Water Use Efficiency – MEWUE – to satisfy these concerns. We intend MEWUE to address the objections stakeholders voiced with other suggested terms, and to define our scope of inquiry as uses of water dedicated to the environment through human management.

Appropriately implemented, MEWUE would be a systematic method of measuring and improving the benefits of specific environmental water uses. It would also allow evaluation of the relative efficiency of one use of managed environmental water over another. MEWUE would replace implicit assumptions about the efficiency of managed environmental water with explicit assessment. MEWUE can also provide a mechanism for improving management over time and increasing accountability for environmental water use decisions.

Many tools that could be used to measure or improve MEWUE are currently in place or are being developed. The condition of California's aquatic environments (including water quality, habitat suitability, etc.) is monitored under a variety of programs and with various techniques. Also, individual restoration projects or ecological flow regimes are often evaluated for effectiveness in meeting some set

⁴⁶ Connick & Innes (2001)

of goals. Successful management practices and standard restoration techniques are identified and publicized. Regulatory changes and interagency management and communication initiatives are occasionally initiated. To a large extent, then, the recommendation of this report is to recognize and embrace these components as ingredients in a system to evaluate and maximize the efficiency of water management for environmental benefits, under the common rubric of MEWUE.

A Comprehensive and Collaborative Approach to Defining and Implementing MEWUE

The identification of the environmental benefits that are gained per unit of water is a difficult and controversial task, given the complexity of any ecological system. Precisely quantifying these benefits is beyond the reach of current science and economics. In the absence of a single measure, whatever method is used to determine these benefits should be as comprehensive as possible to accommodate the range of values associated with healthy ecosystems. Single species metrics will generally not be sufficient. However, a modification of the variety of ecological assessment techniques and metrics presently available could be constructed to act as a standardized measure of ecological benefits, at least within ecoregions.

Potential Approaches to Implementing MEWUE

- Employ quantitative ecological monitoring and evaluation programs to create baseline data, monitor trends and aggregate performance, and perform targeted efficiency assessment of individual projects.
- Perform instream flow requirements analysis to establish habitat goals for California's aquatic habitats.
- Further develop the role of non-market economic valuation in cost-benefit analysis of alternative projects and management regimes.
- Establish a benchmarking process for environmental water management.
- Create a process for establishing Best Management Practices for environmental water uses.
- Create an interagency collaborative working group for environmental water management decision-making, program and regulatory harmonization, and coordination of research.

Furthermore, there are ongoing efforts to improve environmental water use and ecosystem restoration projects, but they have not been recognized as measures that increase the efficiency of managed environmental water uses. We recommend populating MEWUE with a variety of efficiency-promoting practices. These practices include instream flow assessments, project auditing, benchmarking, and best management practices.

Given the variety of viable approaches and the diversity of stakeholder perspectives, we recommend an ongoing collaborative process (similar to those conducted by CALFED) to define and implement MEWUE. We view such an approach as important in ensuring a comprehensive and mutually acceptable approach to solving the difficult benefits evaluation issue. A collaborative approach would also facilitate improvements in interagency communication and decision-making structures.

We do not provide in this report a single answer or approach for defining and implementing MEWUE. Rather, we have demonstrated the importance of the concept and introduced the idea that many practices championed by various stakeholders can play a part in MEWUE. We hope that this report provides a

term and concept around which a collaborative discussion can be structured about how best to implement this concept.

Summary of Key Points

- This report provides a term and concept around which a collaborative process can be structured.
- Despite perceived disagreement about WUE for the environment, there is consensus that environmental water management should strive to achieve the greatest amount of benefit possible from the water made available.
- MEWUE – Managed Environmental Water Use Efficiency – is a suitable term to express this goal.
- Multiple current efforts and practices are related to MEWUE, and potentially can be incorporated into its implementation.
- Although precise quantification of environmental benefits is exceedingly complex, ecological indicators can provide useful measurements of ecosystem health and instream flow requirements can provide management goals. Benchmarking and Best Management Practices are techniques that could operationalize MEWUE.
- Given the variety of viable approaches and the diversity of stakeholders, an ongoing collaborative process (similar to those conducted by CALFED) can help define and implement MEWUE.

APPENDIX A: State Water Plan Update 2003 Public Advisory Committee Members

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|-----------------------|--|
| Margit Aramburu | Delta Protection Commission |
| Mary Bannister | Pajaro Valley Water Management Agency |
| Kirk Brewer | California Water Association |
| Merita Callaway | California State Association of Counties |
| Scott Cantrell | California Department of Fish and Game, Sacramento |
| Grace Chan | Metropolitan Water District of Southern California, Los Angeles |
| Jim Chatigny | Mountain Counties Water Resources Association |
| Marci Coglianese | League of California Cities, Rio Vista |
| Bill Cunningham | U.S. Natural Resources Conservation Service, Davis |
| Grant Davis | Bay Institute of San Francisco, San Rafael |
| Martha Davis | Inland Empire Utilities Agency, Rancho Cucamonga |
| Mary Ann Dickinson | California Urban Water Conservation Council, Sacramento |
| Nick Di Croce | California Trout, Solvang |
| Anisa Divine | Imperial Irrigation District |
| William DuBois | California Farm Bureau Federation, Sacramento |
| Howard Franklin | Monterey County Water Resources Agency |
| Lloyd Fryer | Kern County Water Agency, Bakersfield |
| Bill Gaines | California Waterfowl Association, Sacramento |
| Fran Garland | ACWA, Contra Costa Water District, Concord |
| Peter Gleick | Pacific Institute for Studies in Development, Environment, and Security, Oakland |
| Zeke Grader | Pacific Coast Federation of Fishermen's Associations, San Francisco |
| Brent Graham | Tulare Lake Basin WSD, Corcoran |
| David Guy | Northern California Water Association |
| Martha Guzman | California Rural Legal Assistance Foundation |
| Alex Hildebrand | South Delta Water Agency, Manteca |
| Mike Hoover | U.S. Fish and Wildlife Service |
| Bill Jacoby | WateReuse Association, San Diego |
| Craig Jones | State Water Contractors, Inc., Sacramento |
| Rachel Joseph | Lone Pine Paiute-Shoshone Tribe |
| Kevin Kauffman | Stockton East Water District, Stockton |
| Joseph Lima | ACWA, Modesto Irrigation District, Modesto |
| Jay Lund | University of California, Davis |
| Steve Macaulay | California Urban Water Agencies, Sacramento |
| Jennifer Martin | The Nature Conservancy, San Francisco |
| Benjamin Magante, Sr. | San Luis Rey Indian Water Authority |
| William Miller | Consulting Engineer, Berkeley |
| John Mills | Regional Council of Rural Counties |
| Clifford Moriyama | California Business Properties Association, Sacramento |
| Valerie Nera | California Chamber of Commerce, Sacramento |
| James Noyes | Southern California Water Committee, Inc., Ontario |
| Enid Perez | Del Rey Community Services District, Del Rey |

| | |
|---------------------|--|
| Lloyd Peterson | U.S. Bureau of Reclamation, Sacramento |
| Cathleen Pieroni | City of San Diego Water Department |
| Nancy Pitigliano | Tulare County Farm Bureau, Tipton |
| Robert Quitiquit | Robinson Rancheria, Nice |
| Betsy Reifsnider | Friends of the River, Sacramento |
| Terry Roberts | Governor's Office of Planning and Research |
| Larry Rohlfes | California Landscape Contractors Association, Sacramento |
| Spreck Rosekrans | Environmental Defense |
| Jennifer Ruffolo | California Research Bureau |
| Steve Shaffer | California Department of Food and Agriculture, Sacramento |
| Polly Osborne Smith | League of Women Voters of California, Tiburon |
| Jim Snow | Westlands Water District, Fresno |
| Frances Spivy-Weber | Mono Lake Committee, Redondo Beach |
| John D. Sullivan | League of Women Voters, Claremont |
| Walter Swain | U.S. Geological Survey, Sacramento |
| Greg Thomas | Natural Heritage Institute, Berkeley |
| Michael Wade | California Farm Water Coalition, Sacramento |
| Michael Warburton | The Ecology Center, Berkeley |
| Tom Ward | California Department of Parks & Recreation |
| Brian White | California Building Industry Association |
| Arnold Whitridge | Trinity County |
| Robert Wilkinson | University of California Santa Barbara |
| Kourt Williams | Executive Partnership for Environmental Resources Training, Inc. |
| Carolyn Yale | U.S. Environmental Protection Agency, San Francisco |
| Gary Yamamoto | California Department of Health Services, Sacramento |
| Tom Zuckerman | Central Delta Water Agency |

APPENDIX B: Interview Questions⁴⁷

Background

What do you work on? How is this concept relevant to your interests and those of your organization?

The WUE concept

When you hear the term “water use efficiency,” what is your reaction? What do you understand the term to mean generally?

To you, what should Ecosystem Restoration Water Use Efficiency mean?⁴⁸ What is the concept fundamentally about? What should it measure (regardless of whether it can or not)?

What, specifically, are you most interested in changing through this concept? If this concept will not change whatever you feel is the critical issue, what would?

If conducted correctly, what good will come out of the process of defining and implementing this concept?

What, if anything, concerns you about the process of defining and implementing WUE? Are there critical interests that you fear may be compromised by this endeavor? What, specifically, are they?

Existing Reference Points

Do you have examples of water use for ecosystem restoration that is inefficient or could be more efficient?

Do you see any significant regulatory barriers to WUE? What, specifically, are they? Are there new regulatory approaches that could facilitate the concept?

How do you feel that your concept of ecosystem restoration efficiency might be measured? Are you aware of any existing literature that you find particularly applicable/compelling? What ecological indicator methods are you aware of that might be specifically relevant to this project?

How do you currently measure/assess the merit of restoration projects at this time (assuming you think about such things)?

Are you aware of approaches to this problem that you consider best management practices?

Have you done work on this concept before? Are you aware of others who have, or others we should talk to for whatever reason? Who? How about the parallel concept for other uses (agricultural/urban water use)?

⁴⁷ These questions served as the basis for our conversations with stakeholders and often we did not ask them verbatim. Rather, the questions served to guide these interviews and ensured that major points would be addressed during the course of our conversations.

⁴⁸ At the time we prepared this questionnaire, Ecosystem Restoration WUE was the term in use.

Current Project

What do you feel would be the most potentially beneficial outcomes of the GSPP team’s work on this issue? What specific outputs would you find valuable? How can we be helpful to you and to the problem?

How do you feel about the interaction of different actors and stakeholders who participate in the water planning process? How do you feel this process could be improved?

APPENDIX C: Economic Valuation Methods⁴⁹

Market Price Method

Estimates economic values for ecosystem products or services that are bought and sold in commercial markets.

Productivity Method

Estimates economic values for ecosystem products or services that contribute to the production of commercially marketed goods.

Hedonic Pricing Method

Estimates economic values for ecosystem or environmental services that directly affect market prices of some other good. Most commonly applied to variations in housing prices that reflect the value of local environmental attributes.

Travel Cost Method

Estimates economic values associated with ecosystems or sites that are used for recreation. Assumes that the value of a site is reflected in how much people are willing to pay to travel to visit the site.

Damage Cost Avoided, Replacement Cost, and Substitute Cost Methods

Estimates economic values based on costs of avoided damages resulting from lost ecosystem services, costs of replacing ecosystem services, or costs of providing substitute services. Most famous example is New York City's estimation of the value of watershed protection and enhancement, based on avoided costs of drinking water treatment.

Contingent Valuation Method

Estimates economic values for virtually any ecosystem or environmental service. The most widely used method for estimating non-use, or "passive use" values. Asks people to directly state their willingness to pay for specific environmental services, based on a hypothetical scenario.

Contingent Choice Method

Estimates economic values for virtually any ecosystem or environmental service, based on asking people to make tradeoffs among sets of ecosystem or environmental services or characteristics. Does not directly ask for willingness to pay—this is inferred from tradeoffs that include cost as an attribute.

Benefit Transfer Method

Estimates economic values by transferring existing benefit estimates from studies already completed for another location or issue.

⁴⁹ *Ecosystem Valuation*. U.S. Department of Agriculture Natural Resources Conservation Service and National Oceanographic and Atmospheric Administration. 1 March 2004 <<http://www.ecosystemvaluation.org/>>.

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MEMORANDUM

To: Kamyar Guivetchi, DWR

CC: Michael Perrone, DWR, B160 Advisory Committee Members

From: Spreck Rosekrans and Ann Hayden

Date: December 8, 2003

Subject: Quantification of Unmet Environmental Objectives in State Water Plan 2003 using actual flow data for 1998, 2000, and 2001.

As requested, we are re-submitting the following summary of our preliminary analysis of existing unmet environmental flow objectives. We greatly appreciate the feedback we recently received from DWR staff and have incorporated suggestions accordingly, which will be discussed in greater detail below. Due to time constraints, this analysis was conducted on only a partial list of objectives; we strongly encourage DWR to conduct a more rigorous analysis of unmet environmental objectives statewide.

Statewide, numerous environmental flow objectives exist that continue to go unmet, such as federal and State legal mandates to double salmon populations. The purpose of our analysis is to identify and quantify these gaps. Whether these objectives are adequately met under these alternative scenarios in the State Water Plan update is a matter for staff and AC consideration, but we hope that providing a quantified summary of such objectives will shed some light on what is actually occurring.

At the core of many of these environmental flow objectives is the goal of re-creating the natural hydrograph in systems impaired by water storage projects. By establishing appropriate flows, riverine ecosystems processes can be maintained, such as channel and riparian vegetation corridor maintenance, and ultimately the maintenance of aquatic species populations can occur.

The primary difference between this updated analysis and our previous analysis is the use of actual flow data for 1998, 2000, and 2001 representing a wet, normal and dry year, respectively. This approach is in contrast to our previous application of CALSIM, a model based on historical flow. Since there are many unresolved issues as to how CALSIM should be used in the State Water Plan update, we decided for the sake of consistency we would use actual flow data. It should be noted, however, that there are some limitations or possible inaccuracies when using actual flows. For instance, higher B2 flows were in place in 1999 before the new policy came out which significantly changed how the water was accounted for; therefore, some of the unmet flow needs may appear to be lower using actual flow data than they would be today.

As a preliminary analysis, we chose the following objectives to be quantified:

- Trinity River flows consistent with Trinity River Mainstem Restoration Plan ROD (fall 2000).
- Additional water required meeting the flow objectives in the “Final Restoration Plan for the Anadromous Fish Restoration Program” (2001).
- A level of protection in the Bay-Delta that is equivalent to that specified by CALFED ROD, and required for long-term ESA assurances. This includes a viable Environmental Water Account, the

Interior decision for CVPIA B2 water that allows crediting within metrics (i.e. pre offset-reset ruling) and a fully functional Tier 3.

- San Joaquin flows needed to comply with the federal court order to restore the salmon fishery below Friant Dam.
- All Level 4 Refuge Supplies.
- The Ecosystem Restoration Program purchases identified in the CALFED ROD for Stage One implementation to be used to meet the flow objectives outlined in the CALFED Final EIR/EIS (July 2000).
- San Joaquin River flows at Vernalis consistent with levels specified in the 1995 Water Quality Control Plan.

A preliminary assessment of quantified unmet environmental objectives for these locations is provided in a summary table and discussion below. It's worth mentioning that there is considerable variability in the extent to which there is conflict between meeting these objectives and meeting water delivery objectives for the urban and agricultural sectors.

Summary

Our analysis suggests the following quantities for the selected unmet objectives. Note that in some cases, there would be an effect on consumptive use and in other cases no effect. For example, American River flows might be recaptured in the Delta, while Trinity River flows would not be recaptured.

| | American (Nimbus) | Stanislaus (Goodwin) | ERP #1 Flow Obj. | ERP #2 Flow Obj. | ERP #4 Freeport (Dayflow) | Trinity (Lewiston) | SJR at Vernalis (Dayflow) | SJR below Friant | Level 4 Refuges | Total (TAF) |
|----------------|------------------------------|---------------------------------|-----------------------------|-----------------------------|--|-------------------------------|--|---------------------------------|----------------------------|------------------------|
| WY 1998 | 25 | 7 | 0 | 0 | 0 | 168 | 97 | 0 | 125 | 422 |
| WY 2000 | 55 | 34 | 0 | 65 | 0 | 344 | 96 | 268 | 125 | 987 |
| WY 2001 | 81 | 0 | 0 | 76 | 242 | 99 | 62 | 313 | 125 | 998 |

American River

Existing American River flows were identified on the California Data Exchange Center (CDED) database website as the flows below Nimbus reservoir. Objectives for the American River are outlined in the Anadromous Fish Restoration Program¹. This analysis determined an annual average deficiency of environmental flows of 25 TAF in 1998, 55 TAF in 2000, and 81 TAF in 2001.

Stanislaus River

Existing Stanislaus River flows were identified on the CDEC database as the flows below Goodwin dam. Objectives for the Stanislaus River are outlined in the AFRP. This analysis determined an annual average deficiency of environmental flows of 7 TAF in 1998, 34 TAF in 2000, and 0 TAF in 2001.

Ecosystem Restoration Program

The CALFED Ecosystem Restoration Program focuses on the connection between meeting the flow needs on the Sacramento, Feather, Yuba, American, Mokelumne, Tuolumne, and Merced Rivers and the

¹ Final Program for the Anadromous Fish Restoration Program, 2001

freshwater inflow needs in the Delta. The ERP includes three quantifiable flow objectives for each year type, including Target 1: March outflow, Target 2: late-April to early May outflow, and Target 4: May flows on the Sacramento River². For the purposes of this analysis, for Target 2, we assumed the ERP pulse flow would occur in the wetter period, which typically was in April. For all the targets, the target flows had to occur for ten days and we assumed flat flows across the month. Existing flows for each of these targets are identified using Interagency Estuary Project (IEP) Dayflow database. This analysis determined the following average deficiency of environmental flows: ERP #1: 0 TAF in 1998, 0 TAF in 2000, and 0 TAF for 2001. ERP #2: 0 TAF in 1998, 65 TAF in 2000, and 76TAF in 2001. ERP #4: 0 TAF in 1998, 0 TAF in 2000, and 242 TAF in 2001.

Trinity River

Existing Trinity River flows were identified on the CDEC database as the flows below Lewiston Reservoir.³ Daily flow objectives for the Trinity River are from the Trinity River ROD. This analysis determined an average deficiency of environmental flows of 168 TAF in 1998, 344 TAF in 2000, and 99 TAF in 2001.

San Joaquin River at Vernalis

Existing flows for the San Joaquin at Vernalis were identified using Dayflow data. Flow objectives at Vernalis are identified in the 1995 Water Quality Control Plan and occur from April 15-May 15. This analysis determined an average deficiency of 97 TAF in 1998, 96 TAF in 2000, and 62 TAF in 2001.

San Joaquin River below Friant

San Joaquin River flow objectives are based on a URS Report⁴, completed as part of the settlement process between NRDC and the Friant Water Users Authority. Currently, 117 TAF flow are annually released down the San Joaquin River to satisfy downstream prior-right riparian water user and contract objectives.

The environmental flow objectives for the San Joaquin River are provided in the water quality study and determined an annual average deficiency of 0 TAF in 1998, 268 TAF in 2000, and 313 TAF in 2001.

Level 4 Refuges

As prescribed in the CVPIA, Level 4 Refuge Water is the water needed in addition to current average annual water deliveries (Level 2 Refuge Water) to 19 Sacramento and San Joaquin refuges⁵. Incremental Level 4 water is based on 10% increments of water to be delivered to the refuges until year 10 (2002) when it was expected the full amount would be attained. To date, this amount has not been largely due to funding limitations and the growing cost of water (e.g.: average cost of water has increased from \$50-60/af in 1995 to \$125-\$150/af in just eight years). Moreover, necessary construction of refuge conveyance systems has not occurred at a number of refuges, further limiting the supply of water to the refuges. The annual unmet environmental water needs at Level 4 Refuges was 125 TAF for 1998, 2000, and 2001.

² “Volume II: Ecosystem Restoration Program Plan, Sacramento-San Joaquin Delta Ecological Management Zone Vision,” July 2000, pages 97-99.

³ <http://cdec.water.ca.gov/>

⁴ “Water Supply Study: Development of Water Supply Alternatives for Use in Habitat Restoration for the San Joaquin River”, URS, 2003.

⁵ Summary of Refuge Needs, Dale Garrison, USFWS, 2003.

EWA and B2

The B2 Account and EWA are environmental obligations prescribed in the CVPIA and CALFED ROD, respectively, to provide benefits to fisheries and aquatic habitat in the Central Valley and Bay-Delta. In terms of B2, Interior's most recent 2003 policy for managing B2 supplies has significantly diminished the amount of water available for protection and restoration. As for the EWA, while protective operations have had some positive effects on aquatic habitat and the health of the Delta's fisheries, gaps in this account still exist. The size and operation of the EWA is currently being revised in light of changes to state and federal water operations.

While the above preliminary analysis provides much needed information on unmet needs, there are still many other environmental water objectives that need to be quantified. A truly comprehensive analysis would include environmental water legal mandates that occur statewide, extending from the Klamath River in the north to the Salton Sea in the south. Even in the Bay-Delta, more quantification is necessary. Unfortunately, while data exists to analyze some of these objectives, there are significant gaps in data collection throughout the state--a fact that requires serious attention and action from relevant agencies. We strongly encourage DWR to fill these data gaps where possible and complete a total assessment of unmet environmental objectives throughout the state.

Evapotranspiration

| | |
|---|----|
| CUP (Consumptive Use Program) Model, <i>Morteza Orang, Richard Snider, Scott Matyac (Department of Water Resources and University of California Davis)</i> | 3 |
| Evapotranspiration and Relative Contribution by the Soil and the Plant | 15 |
| SIMETAW (Simulation of Evapotranspiration of Applied Water), <i>Richard Snider, Morteza Orang, Shu Geng, Scott Matyac. Sara Sarreshteh (University of California Davis and Department of Water Resources)</i> | 47 |

Consumptive Use Program Model

The California Department of Water Resources (DWR) and the University of California (UC) have developed a user-friendly Excel application program (CUP) to improve the dissemination of K_c and crop evapotranspiration (ET_c) information to California growers and water purveyors. CUP computes reference evapotranspiration (ET_o) from monthly means of solar radiation, maximum and minimum temperature, dew point temperature, and wind speed using the daily Penman-Monteith equation. The program uses a curve fitting technique to derive one year of daily weather and ET_o data from the monthly data. In addition, daily rainfall data are used to estimate bare soil evaporation as a function of mean of ET_o and wetting frequency in days. A bare soil K_c value is calculated to estimate the off-season evapotranspiration and as a baseline for in-season K_c calculations. CUP accounts for the influence of orchard cover crops on K_c values and it accounts for immaturity effects on K_c values for tree and vine crops. Further, the program computes and applies all ET_o and K_c values on a daily basis to determine crop water requirements by month, by season, by year.

Methodology

Reference Evapotranspiration (ET_o) Calculation

Reference evapotranspiration (ET_o) is estimated from daily weather data using a modified version of the Penman-Monteith equation [1]. The equation is:

$$ET_o = \frac{0.408 \Delta (R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34 u_2)} \quad (1)$$

where Δ is the slope of the saturation vapor pressure at mean air temperature curve ($\text{kPa } ^\circ\text{C}^{-1}$), R_n and G are the net radiation and soil heat flux density in $\text{MJ m}^{-2}\text{d}^{-1}$, γ is the psychrometric constant ($\text{kPa } ^\circ\text{C}^{-1}$), T is the daily mean temperature ($^\circ\text{C}$), u_2 is the mean wind speed in m s^{-1} , e_s is the saturation vapor pressure (kPa) calculated from the mean air temperature ($^\circ\text{C}$) for the day, and e_a is the actual vapor pressure (kPa) calculated from the mean dew point temperature ($^\circ\text{C}$) for the day. The coefficient 0.408 converts the $R_n - G$ term from $\text{MJ m}^{-2}\text{d}^{-1}$ to mm d^{-1} and the coefficient 900 combines together several constants and converts units of the aerodynamic component to mm d^{-1} . The product $0.34 u_2$, in the denominator, is an estimate of the ratio of the 0.12-m tall canopy surface resistance ($r_c=70 \text{ s m}^{-1}$) to the aerodynamic resistance ($r_a=205/u^2 \text{ s m}^{-1}$). It is assumed that the temperature, humidity and wind speed are measured between 1.5 m (5 ft) and 2.0 m (6.6 ft) above the grass-covered soil surface. If only temperature data are available, the Hargreaves-Samani equation is used. The equation may be written:

$$ET_o = 0.0023 (T_c + 17.8) R_a (T_d)^{1/2} \quad (2)$$

Where, T_c is the monthly mean temperature (degrees centigrade), R_a is the extraterrestrial solar radiation expressed in mm/month , and T_d is the difference between the mean minimum and mean maximum temperatures for the month ($^\circ\text{C}$).

If pan data are input into the program, then the program automatically converts monthly pan evaporation data to ET_o estimates using the latest methodology. The new method in the CUP estimates ET_o from E_{pan} data using a fetch value (i.e., upwind distance of grass around the pan) without the need for wind speed and relative humidity data.

Validation and Comparison of CUP with Other Methods

Nine years of estimated daily ET_o data from CIMIS (California Irrigation Management Information System) at Davis, California were used to validate our model predictions of ET_o . Figure 1 compares daily mean ET_o estimates of CUP and CIMIS averaged over the period of the data set at Davis, California. The performance of the CUP was further evaluated at a humid location (Port Hueneme) and windy desert site (Bishop). As seen in Figures 1-3, a close agreement between CIMIS-based estimates of ET_o and those of the CUP model exists. Davis is in the Central Valley, which is characterized by clear, hot, dry days with strong, cooling southwest winds during afternoons in the summer. Port Hueneme is in Ventura County with coastal cool, humid weather patterns. Bishop is influenced by a windy desert environment on the eastern side of the Sierra Nevada range.

Figure 1
Comparison of daily ET_o estimates from CUP, SIMETAW, and CIMIS at Davis, California

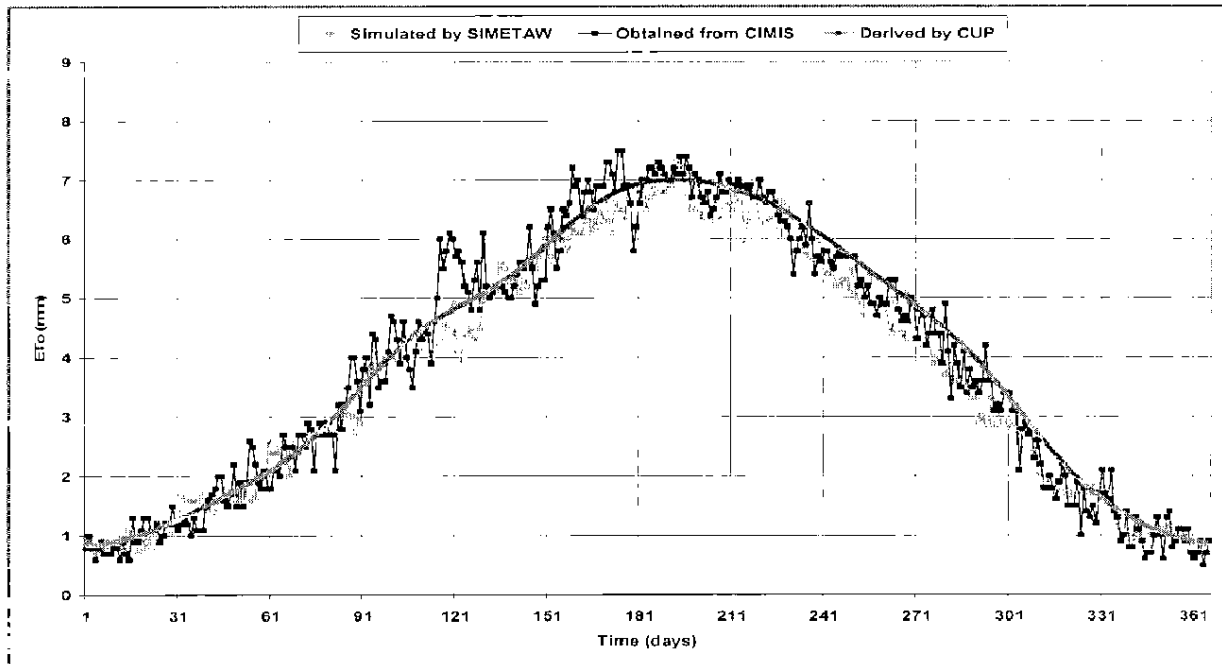


Figure 2
Comparison of daily ET_o estimates from CUP, SIMETAW and CIMIS at Port Hueneme, California

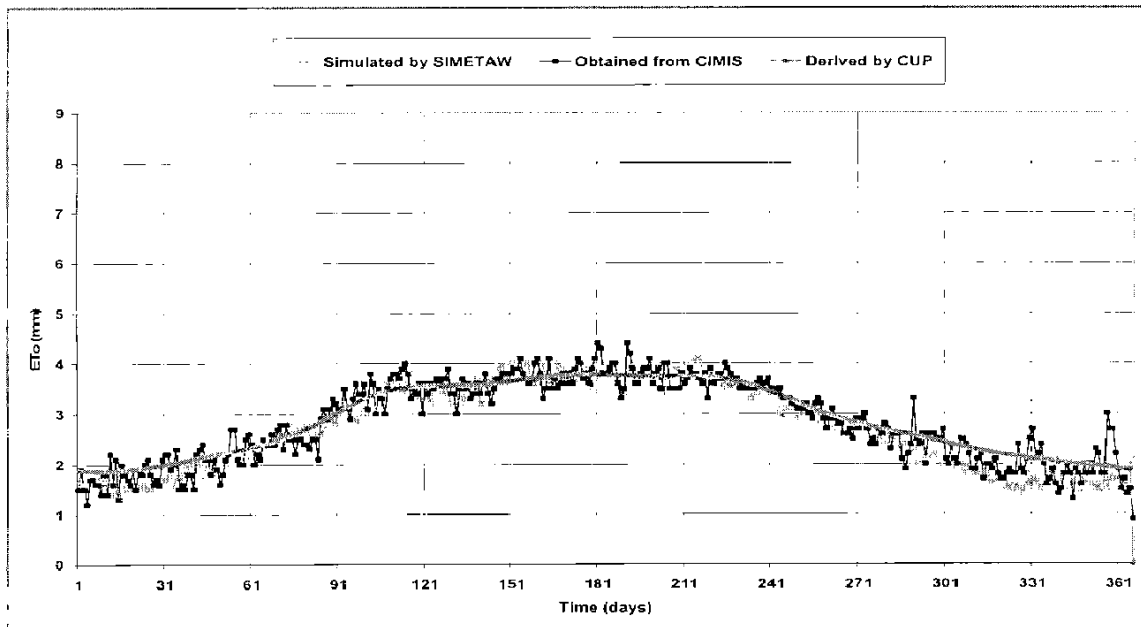
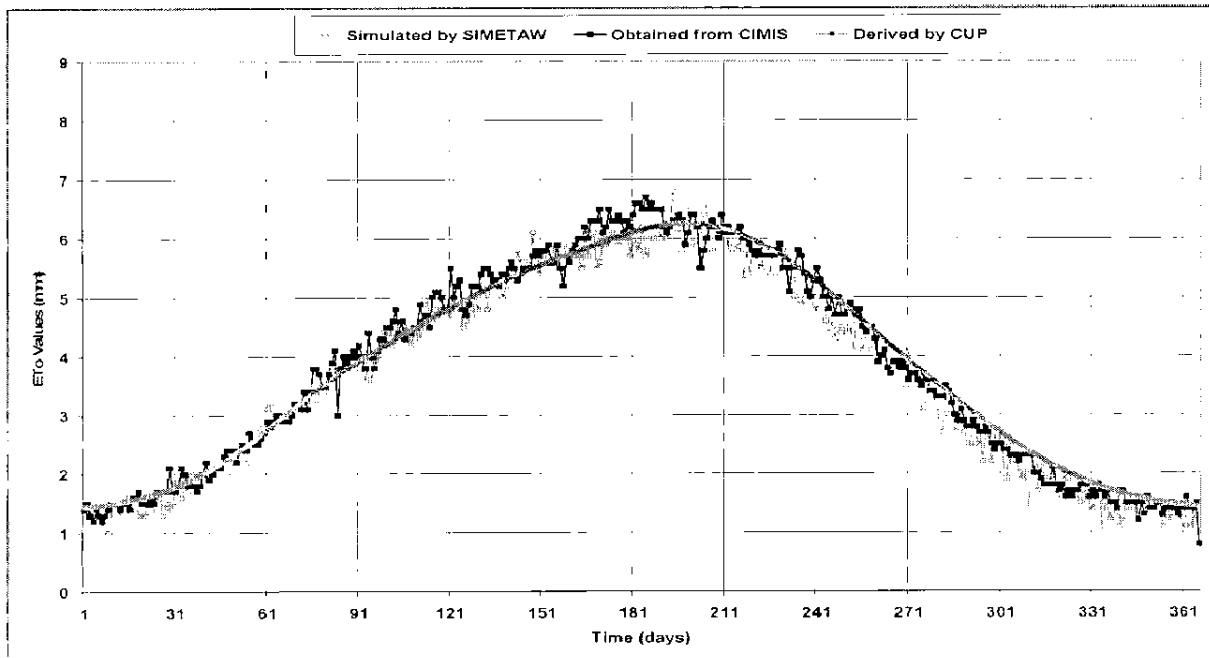


Figure 3
Comparison of daily ET_o estimates from CUP, SIMETAW, and CIMIS at Bishop, California



Daily Weather Output Accuracy

One of objectives of the CUP model is use a curve fitting technique to produce one year of daily weather data from 12 monthly mean values. Monthly mean values of measured weather data averaged over the period of the data set (1990 – 1998) from the California Irrigation Management Information System (CIMIS) in Davis were used in the model to derive one year of daily weather data. The weather data consist of R_s , T_{max} , T_{min} , wind speed, T_{dew} , and Rainfall. The weather data derived by CUP were compared with the measured and simulated data from CIMIS and SIMETAW, respectively. Results in Figures 4, 5, and 6 showed that R_s , T_{max} , and Rainfall values predicted from CUP were well correlated with those values obtained from CIMIS and SIMETAW. The performance of the CUP was further evaluated at a humid location and windy desert site. In all locations, CUP correlated very well with CIMIS and SIMETAW. Similar results were also observed for T_{min} , wind speed, and T_{dew} data in other locations.

Figure 4
Comparison of measured and predicted daily solar radiation data at Davis, California

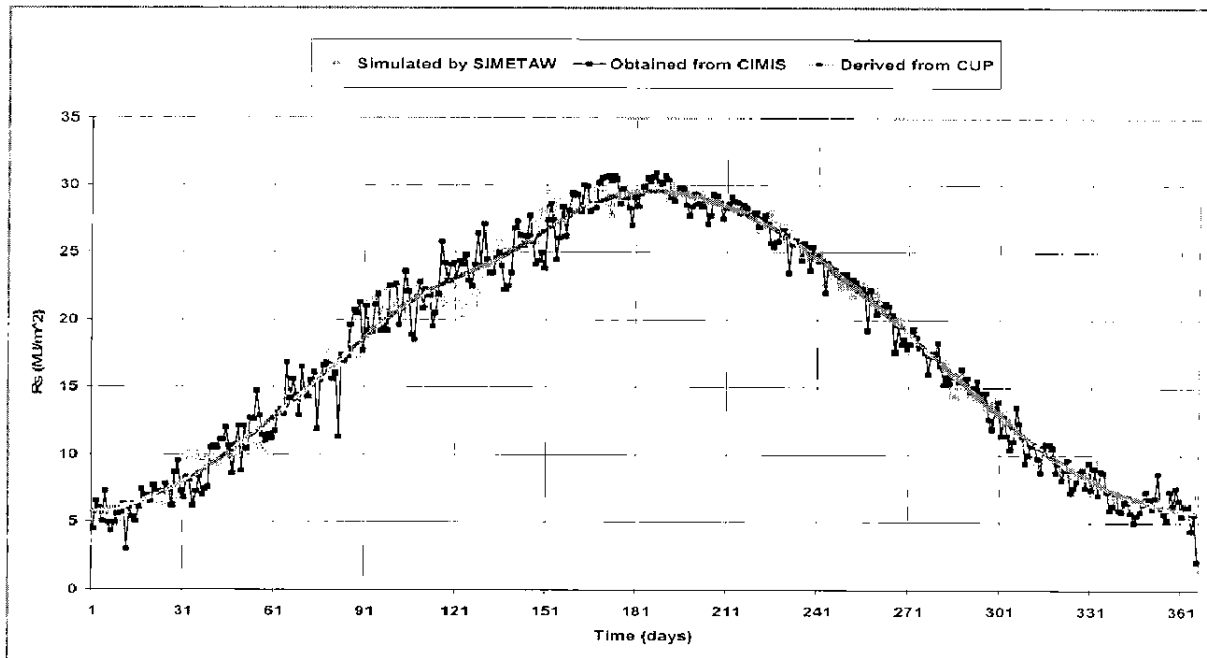


Figure 5
Comparison of measured and predicted daily air maximum temperature data at Davis, California

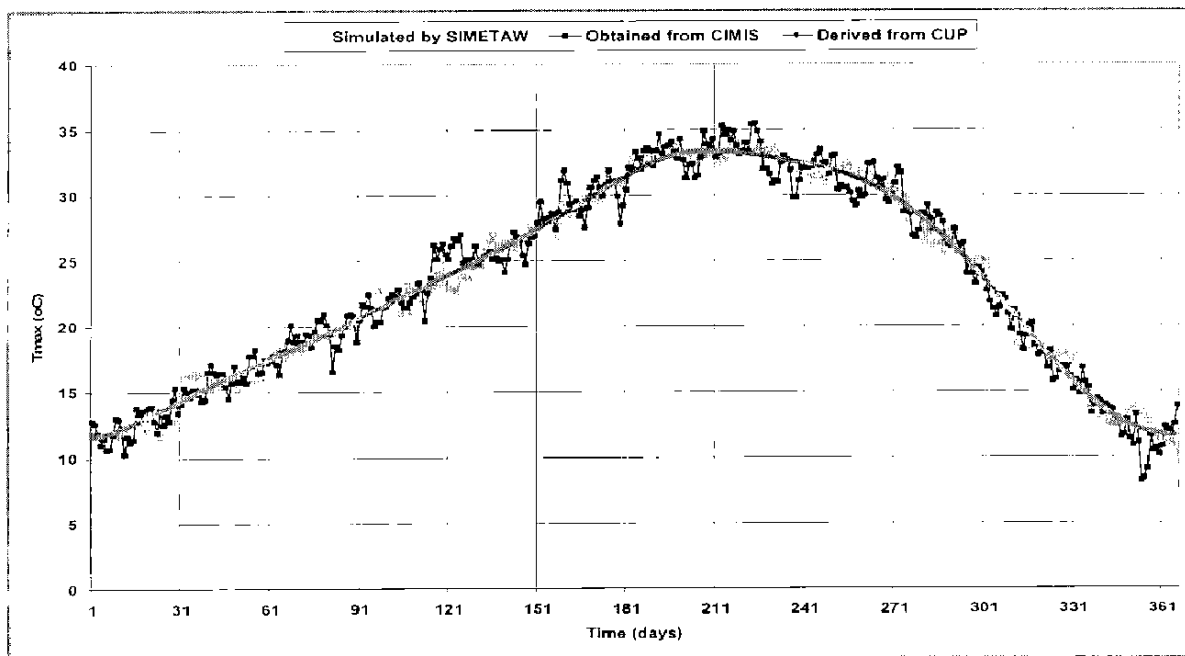
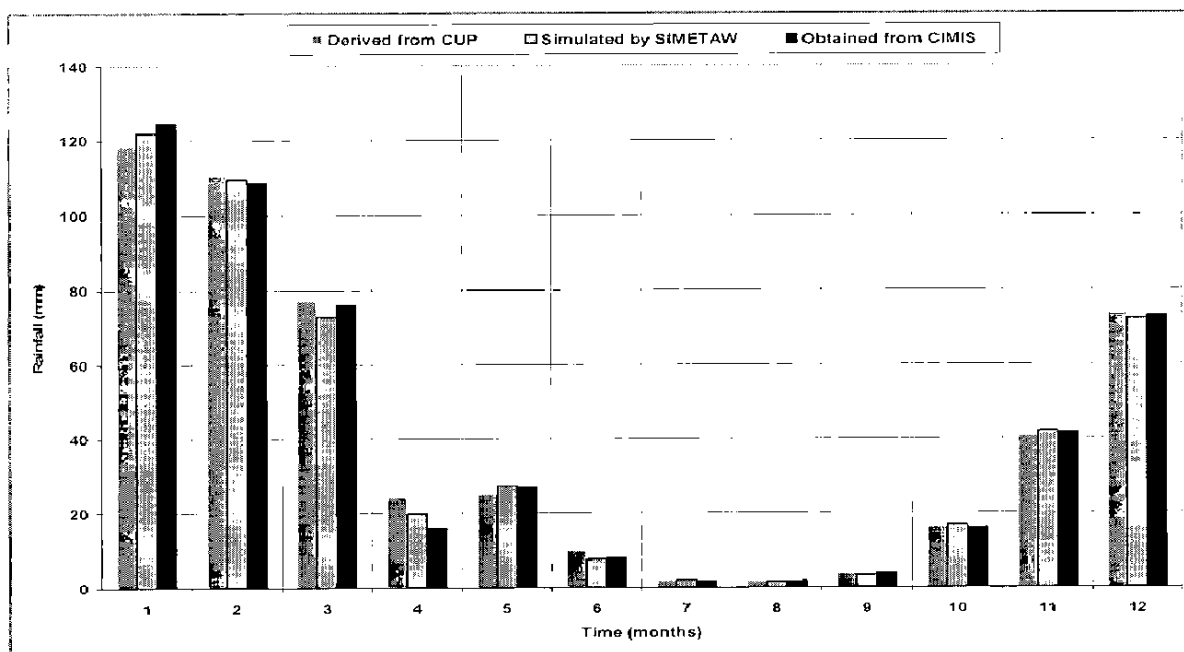


Figure 6
Comparison of monthly total rainfall values from three different methods at Davis, California



Worksheets

CUP has 19 Excel worksheets. The first eight worksheets are 'Disclaimer', 'HelpAbout', 'About Cup', 'HELP', 'ET_o Zones Map', 'ET_o Zones', 'Weather Input' and 'Input_Output'. 'HelpAbout' provides information about the program. 'About CUP' explains the program, 'HELP' explains the various components of the program and provides step-by-step instructions for inputting data into the program. 'ET_o Zones' contains a map showing 18 zones of similar ET_o rates for California. The 'Weather Input' worksheet is used to input monthly mean weather or E_{pan} data to estimate ET_o (or monthly mean ET_o data directly) for estimating crop evapotranspiration (ET_c). If the solar radiation, temperature, humidity and wind speed data are input, then the Penman-Montieth equation is used to calculate ET_o . If only temperature data are input into the table, then the Hargreaves-Samani equation is used to calculate ET_o . If pan data are input, the program automatically estimates daily ET_o rates using a fetch value (i.e. upwind distance of grass around the pan). ET_o and crop data are entered into the 'Input_Output' worksheet, which then displays the summary of inputs and monthly and seasonal outputs. The 'Crop References' worksheet contains a list of crops, crop numbers, estimated growth date, and K_c information. 'Calculation' worksheet shows all of the growth date and K_c as well as the daily calculations of ET_o , K_c and ET_c for each of the growth periods. 'Weather Output' provides one year of daily solar radiation, maximum and minimum temperature, wind speed, dew point temperature, and rainfall data. CUP also outputs one year of daily calculated crop coefficients, ET_o , and ET_c data by crop in the 'Daily ET_c-Output' worksheet. 'Monthly Output' provides monthly total values of ET_o , ET_c , and rainfall during the growing season and off-season.

The ‘ K_c Chart’ worksheet shows a plot of the calculated seasonal crop coefficients with colored lines representing each growth period. ‘ ET_o Chart’ worksheet plots daily ET_o with different colored lines for each growth period. The ‘ ET_o _ ET_c Chart’ provides a bar graph of ET_o and ET_c totals by month during the growing season for the current crop information. There are also summary worksheets for K_c values, ET_o and ET_c . After data entry, the current crop information and calculated K_c data in the ‘Input_Output’ worksheet can be printed to one row in the ‘Summary of Kc’ worksheet. ET_o data are printed to ‘Summary of ET_o ’, and ET_c data are printed to ‘Summary of ET_c ’.

Input-Output Worksheet

Crop information is entered into cells on the left-hand side of the ‘Input_Output’ worksheet. To use monthly mean weather, raw ET_o and pan data, 88 is input into the California ET_o Zone number. Next a crop number is entered into the Crop Number cell. CUP provides a list of crops and crop numbers in the ‘Crop References’ worksheet. That worksheet also contains the percentage of the season to various growth dates (explained later), K_c values at critical growth points, and sample start and end dates for the season.

Note that the crop numbers have one digit to the left and two digits to the right of a decimal point. The single digit identifies the crop type, and the double digit identifies the crop. When a crop is selected, the growth, K_c and default start-end information is automatically used for the calculations. The start date corresponds to planting for field and row crops and to leaf-out date for tree and vine crops. Non-deciduous trees, turfgrass, and pasture crops start on January 1 and end on December 31. If different from the default values, the start and end dates can be changed in the ‘Input_Output’ worksheet.

The initial K_c value for most crops depends on wetting frequency from rainfall and/or irrigation. As the canopy shading increases, the contribution of soil evaporation to ET_c decreases while the contribution of transpiration increases. In the ‘Input_Output’ worksheet, the rainfall frequency during early growth is input to determine a K_c for near bare soil evaporation. Similarly, the irrigation frequency is entered and a K_c determined for near bare-soil evaporation during initial growth of field and row crops. CUP compares K_c values from the Crop References worksheet with those based on rainfall and irrigation frequency and selects the largest of the three for use in calculating ET_c . If no rainfall or irrigation frequency is entered, the K_c from the A-B column in the ‘Crop References’ worksheet is used as the initial growth K_c . The starting K_c for type-2 crops (for example, turfgrass and pasture) and for type-4 crops (for example, subtropical orchards) is not affected by the irrigation or rainfall frequency entries.

Cover crops affect ET_c rates, and CUP accounts for the contributions. The cover crop start and end dates are input into cells under the “Enter 1st Cover Crop (day/mon).” Because some crops have cover crops in spring and fall but not in the summer, a second set of cover crop dates can be input under “Enter 2nd Cover Crop (day/mon)”. During a period with a cover crop, the value 0.35 is added to the “clean cultivated” K_c value. However, the K_c is not allowed to exceed 1.15 or to fall below 0.90.

The right-hand side of the ‘Input_Output’ worksheet shows the weighted mean K_c , ET_o , ET_c , and seasonal ET_c values by month for the selected crop and input information. The daily mean ET_o rates by month are also shown below the other data. Below that set of cells, there are “Copy/Paste” and “Delete” buttons. When the Copy/Paste button is pressed results of the calculations are sent to ‘Summary ET_o ’, ‘Summary Kc’, and ‘Summary ET_c ’ worksheets. The Delete button clears all entries from the summary worksheets.

To retain all of the data entries, save the CUP file as an Excel workbook with a different name. To save only the summary sheets, with the summary sheet displayed, save as a tab or comma delimited file. After saving the desired output data, click the Delete button to erase data from the summary worksheets.

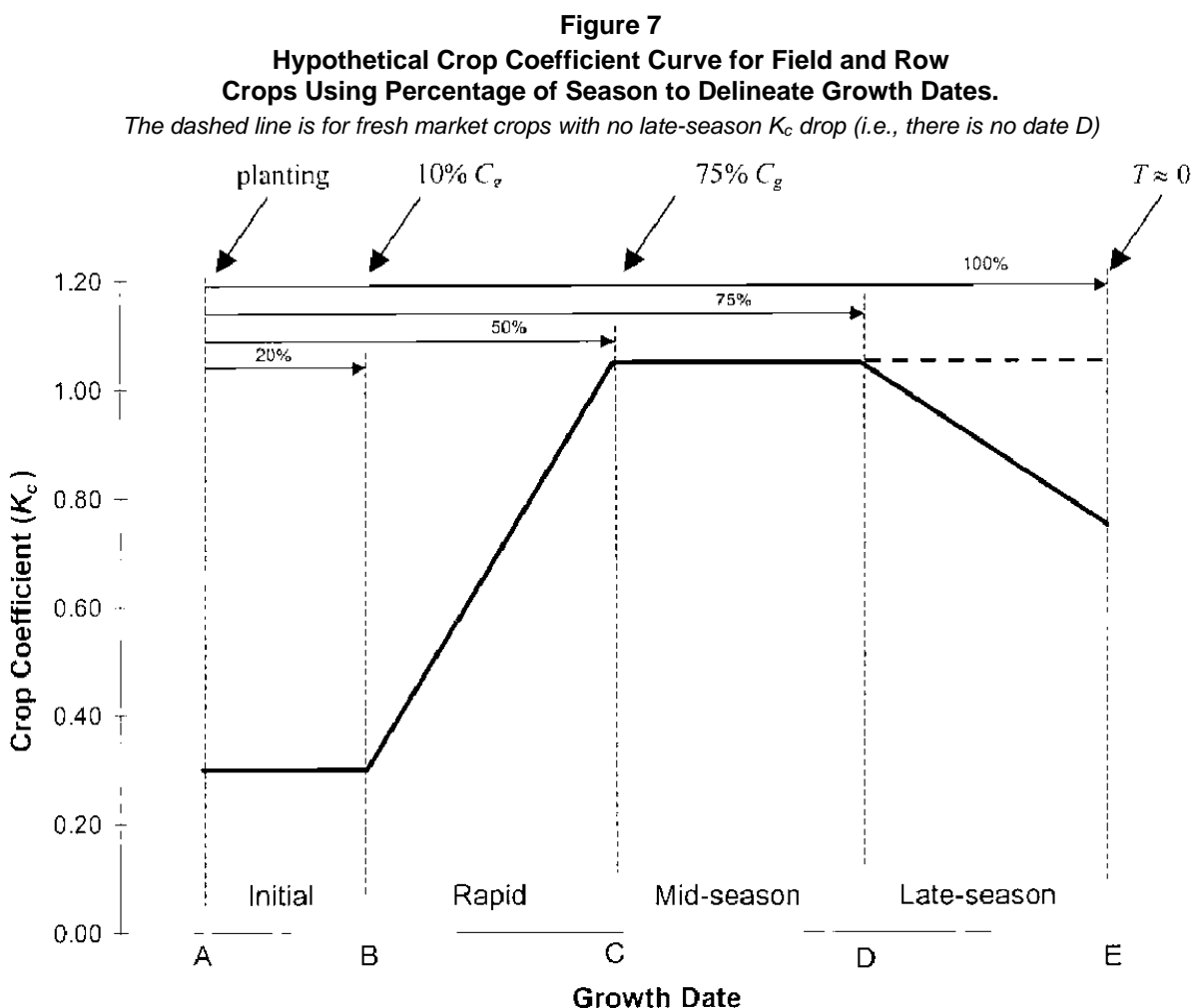
Calculation

The Calculation worksheet shows the selected and input data as well as critical dates for growth and cover crops and the daily calculations of ET_o , K_c and ET_c by the growth stages. The main factors affecting the difference between ET_c and ET_o are (1) light absorption by the canopy, (2) canopy roughness, which affects turbulence, (3) crop physiology, (4) leaf age and (5) surface wetness. When not limited by water availability, both transpiration and evaporation are limited by the availability of energy to vaporize water. Therefore, for unstressed crops, solar radiation (or light) interception by the foliage and soil mainly affect the ET_c rate.

As field and row crops grow, the canopy cover, light interception, and the ratio of transpiration (T) to ET increases until most of the ET comes from T and evaporation (E) is a minor component. The K_c increases with canopy cover until reaching about 75 percent cover. For tree and vine crops the peak K_c is reached when the canopy has reached about 70 percent ground cover. The difference between the crop types is because the light interception is higher for the taller crops.

Field and Row Crop K_c Values

Field and row crop K_c values are calculated using a method similar to that described by Doorenbos and Pruitt [2]. A generalized curve is shown in Fig. 4. In their method, the season is separated into initial (date A-B), rapid (date B-C), midseason (date C-D), and late season (date D-E) growth periods. K_c values are denoted K_{cA} , K_{cB} , K_{cC} , K_{cD} and K_{cE} at the ends of the A, B, C, D, and E growth dates, respectively. During initial growth, the K_c values are at a constant value, so $K_{cA} = K_{cB}$. During the rapid growth period, when the canopy increases from about 10 percent to 75 percent ground cover, the K_c value increases linearly from K_{cB} to K_{cC} . The K_c values are also at a constant value during midseason, so $K_{cC} = K_{cD}$. During late-season, the K_c values decrease linearly from K_{cD} to K_{cE} at the end of the season.



Doorenbos and Pruitt [2] provide estimated number of days for each of the four growth periods to help identify the end dates of growth periods. However, because there are climate and varietal differences and because it is difficult for growers to know when the inflection points occur, irrigators often find this confusing. To simplify this problem, percentages of the season from planting to each inflection point rather than days in growth periods are used (Fig. 4). Irrigation planners need only enter the planting and end dates and the intermediate dates are determined from the percentages, which are easily stored in a computer program.

During initial growth of field and row crops, the default K_c value (K_{c1}) is used for K_{cA} and K_{cB} unless it is overridden by entering a K_c based on rainfall or irrigation frequency. If a soil wetting based K_{c1} is desired, the irrigation or rainfall frequency is entered in the 'Input_Output' worksheet.

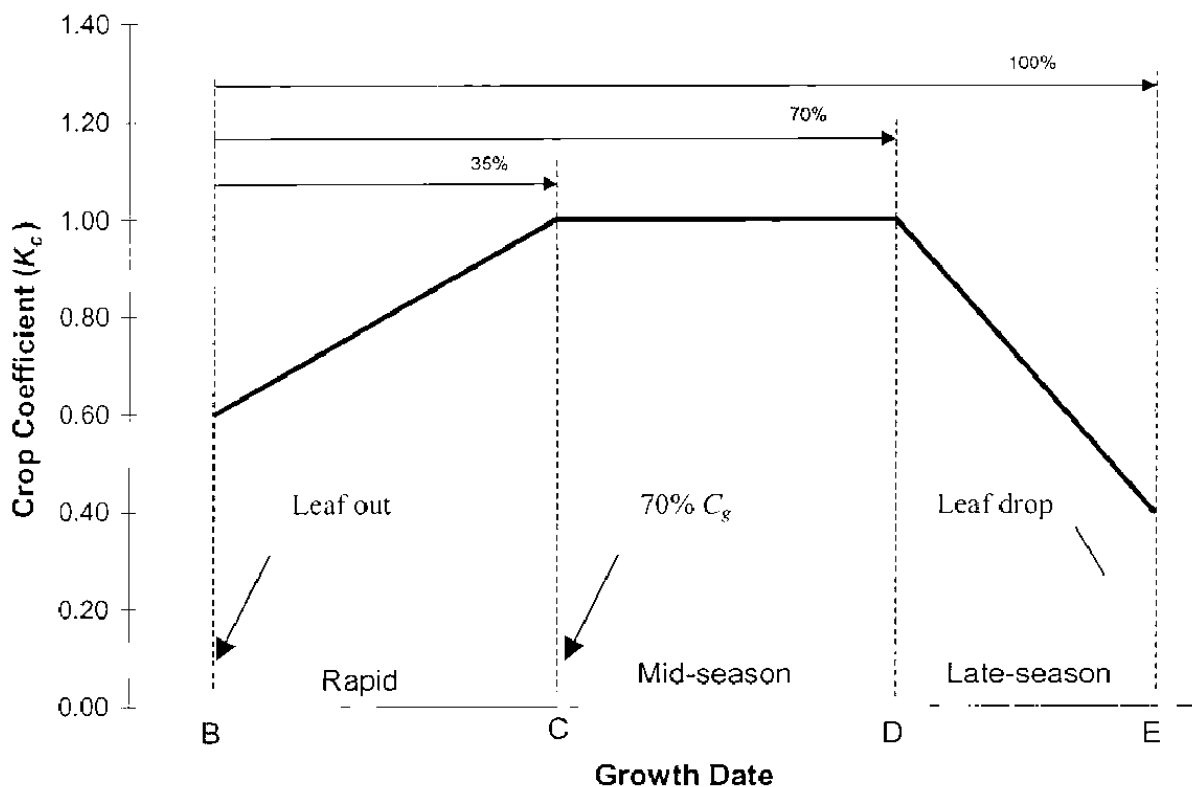
The values for $K_{cC} = K_{cD}$ depend on the difference in (1) light interception, (2) crop morphology effects on turbulence, and (3) physiological differences between the crop and reference crop. Some field crops are harvested before senescence, and there is no late season drop in K_c (for example, silage corn and fresh market tomatoes). Relatively constant annual K_c values are possible for some crops (for example, turfgrass and pasture) with little loss in accuracy.

Deciduous Tree and Vine Crop K_c Values

Deciduous tree and vine crops, without a cover crop, have K_c curves that are similar to field and row crops but without the initial growth period (Fig. 5). Default K_{cB} , $K_{cC} = K_{cD} = K_{c2}$ and $K_{cE} = K_{c3}$ values are given in the Crop References worksheet of the CUP. The season begins with rapid growth at leaf out when the K_c increases from K_{cB} to K_{cC} . The midseason period begins at approximately 70 percent ground cover. Then, unless the crop is immature, the K_c is fixed between dates C and D, which corresponds to the onset of senescence. For immature crops, the canopy cover may be less than 70 percent during the midseason period. If so, the K_c will increase from K_{cC} up to the K_{cD} as the canopy cover increases, so the CUP program accounts for K_c changes of immature tree and vine crops. During late season, the K_c decreases from K_{cD} to K_{cE} , which occurs when the transpiration is near zero.

Figure 8:
Hypothetical Crop Coefficient Curve for Deciduous Tree and
Vine Crops Using Percentage of the Season to Delineate Growth Dates

There is no initial growth period, so the season starts at leaf out on date B



Correcting K_{cB} for Soil Evaporation

Initially, the K_c value for deciduous trees and vines (K_{cB}) is selected from a table of default values. However, the ET is mainly soil evaporation at leaf out, so CUP contains the methodology to determine a corrected K_{cB} , based on the bare soil evaporation.

Correcting for Cover Crops

With a cover crop, the K_c values for deciduous trees and vines are higher. When a cover crop is present, 0.35 is added to the clean-cultivated K_c . However, the K_c is not allowed to exceed 1.15 or to fall below 0.90. CUP allows the beginning and end dates to be entered for two periods when a cover crop is present in an orchard or vineyard.

Immature Trees and Vines

Immature deciduous tree and vine crops use less water than mature crops. The following equation is used to adjust the mature K_c values (K_{cm}) as a function of percentage ground cover (C_g).

$$\text{If } \sqrt{\sin\left(\frac{C_g \pi}{70 \cdot 2}\right)} \geq 1.0 \text{ then } K_c = K_{cm} \text{ or else } K_c = K_{cm} \sqrt{\sin\left(\frac{C_g \pi}{70 \cdot 2}\right)} \quad (3)$$

Subtropical Orchards

For mature subtropical orchards (for example, citrus), using a fixed K_c during the season provides acceptable ET_c estimates. However, if higher, the bare soil K_c is used for the orchard K_c . For an immature orchard, the mature K_c values (K_{cm}) are adjusted for their percentage ground cover (C_g) using the following criteria.

$$\text{If } \sqrt{\sin\left(\frac{C_g \pi}{70 \cdot 2}\right)} \geq 1.0 \text{ then } K_c = K_{cm} \text{ or else } K_c = K_{cm} \sqrt{\sin\left(\frac{C_g \pi}{70 \cdot 2}\right)} \quad (4)$$

Field Crops and Landscape Covers with Fixed K_c Values

Some field crops and landscape plants (type-2 crops) have fixed K_c values all year. However, if the significant rainfall frequency is sufficient to have a higher K_c for bare soil than for the selected crop, then the higher bare soil K_c should be used. CUP permits entry of monthly mean rainfall frequency data. If entered, daily K_c values for bare soil evaporation are computed for the entire year. The higher of the fixed crop K_c or the bare soil K_c is used to estimate ET_c for the crop. If no rainfall frequency data are entered, then the fixed crop K_c is used.

Estimating Bare Soil K_c Values

A soil evaporation K_c value, based on ET_o and rainfall frequency is needed as a minimum (base line) for estimating ET_c . It is also useful to determine the K_c value during initial growth of field and row crops ($K_{c1} = K_{cA} = K_{cB}$), based on irrigation frequency, and the starting K_c for deciduous tree and vine crops ($K_{c1} = K_{cB}$). The K_c values used to estimate bare soil evaporation are based on a two-stage soil evaporation method reported by Stroosnjider [4] and refined by Snyder et al. [3]. The method provides a

K_c values as a function of ET_o rate and wetting frequency that are similar to those published in Doorenbos and Pruitt [2].

If the mean monthly weather and ET_o data are input into the Weather Input worksheet, including the number of significant rainy days per month, CUP calculates a baseline soil evaporation curve. Daily precipitation is considered significant when $P_s > 2 \times ET_o$. Whenever, the K_c for bare soil evaporation is bigger than the K_c based on table or calculated K_c values, the higher K_c value is used.

Extra Features of CUP

CUP application program was written using MS Excel software as a tool to help water agencies, engineers, consultants, educators, and growers obtain accurate estimates of crop water requirement information from monthly mean data. The program takes input weather data and estimates historical means of reference evapotranspiration (ET_o) using the Penman-Montieth equation. If only temperature data are available, the Hargreaves-Samani equation is used. CUP also converts monthly pan evaporation data to ET_o estimates using the latest methodology. In addition, the CUP estimates the annual trend in daily ET_o and weather data. In the past, only monthly, bi-weekly or weekly data were available in the literature and using daily data from CUP improves the ET_c estimation. Alternatively, CUP can select monthly ET_o values from the California ET_o map and it can estimate ET_o from class 'A' pan evaporation using the latest conversion methods. The program helps users to determine improved crop coefficient (K_c) values for estimating crop evapotranspiration (ET_c). Rather than using only linear estimates of the K_c values for various growth stages the CUP accounts for differences in soil evaporation to refine the early season K_c values. The CUP can be used as a tool for teaching and conducting research. In addition, the application outputs a wide range of tables and charts that are useful for irrigation planning. CUP's input and output data are in both English and metric units.

More information on CUP is available at DWR's Web site:

www.waterplan.water.ca.gov/landwateruse/wateruse/Ag/wuagricultural.htm

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Evapotranspiration and Relative Contribution by the Soil and the Plant

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Introduction

A field receives water as rain or irrigation. Some of this water may be lost in liquid form as runoff. Some, after infiltrating the soil, may continue to move deeper as liquid beyond the root zone and into the ground water. Usually, the major loss of water is as vapor, by evaporating from the soil or being transpired by the plants growing on the soil. The liquid loss can be recovered either as ground water or stream flow by users downstream. The water lost as vapor is dissipated in the atmosphere, a huge sink, and cannot be recovered except as precipitation. For all intents and purposes, evapotranspiration from a field, consisting of both water transpired by plants and evaporated from the soil, represents an irreversible loss from that geographical location, and is referred to as consumptive water use.

Evapotranspiration or consumptive water use is usually beneficial, in that plants are grown and produced in exchange for the water used. Plants grow and acquire their biomass (dry weight) by assimilating carbon dioxide from the air via photosynthesis. To acquire carbon dioxide from the air, plants open their stomata, the microscopic control valves on the leaf surface, to let carbon dioxide diffuse into the leaves for photosynthesis. At the same time, water vapor escapes inevitably via the same open valves into the atmosphere. Hence, carbon dioxide assimilation and transpiration (T) are closely associated, and high production is usually linked to high crop water use, as long as that use is the result of transpiration (Tanner and Sinclair, 1983; Hsiao, 1993).

The consumptive use of water through soil evaporation (E), however, is not in exchange for carbon dioxide assimilation. Therefore it is usually considered to be non-beneficial use. This point of view is perhaps slightly too simplistic, and will be discussed in a later section. In any event, in managing the limited water resource of the state of California, it is important to know more accurately how much water crop fields evapotranspire, and how much of the evapotranspiration is due to soil E. It is also important to devise and develop means to minimize the E part of ET. This chapter presents pertinent information bearing on these points and is made up of two parts. The first part discusses ET in terms of the basic principles and important factors determining ET and the quantitative relationships. That is followed by a brief description of the methods used to separate out soil E from plant T, and a review of the literature quantifying the extent of soil E relative to ET. The second part reports on the results of experiments conducted to obtain additional information on the factors affecting ET and the proportion of E in ET, the extent ET is suppressed while water is applied by sprinklers, and the extent that crop T is likely to be increased by minimizing soil E.

Conceptual Background and Analysis of the Literature

Energy Supply for Evapotranspiration and Interactions Between E and T

For water to be evapotranspired, it must be converted from liquid form to vapor form. Water has an unusually high latent heat of vaporization—it takes approximately 2.45 kJ (580 calories) of energy to evaporate one gram of water. For a crop field, virtually all of this energy comes from the aerial

environment. By far the most important source of energy for ET is solar radiation absorbed by the field. This is known as net radiation transfer and consists of the incoming radiation minus the outgoing radiation. A minor source is the direct heating of the crop and soil by air going over the field, which occurs only when the air is warmer than the crop and the soil. This energy supply is termed sensible heat transfer. For many situations, the absorbed radiation is so dominating that daily or weekly ET from a fully wet field can be estimated from the net radiation over the field for the same period. The energy supplied by net radiation is divided by the latent heat of vaporization to obtain the amount of water evapotranspired. Such estimates often fall within 5 or 10 percent of the true ET. Deviation is caused by the warming or cooling of the field by the overhead air mass. ET (when converted to energy units) would be greater than net radiation if the air has a net warming effect on the field, and would be less if the air is mostly cooler than the field and has a net cooling effect.

If the rate of energy supplied as net radiation is suddenly reduced for an evapotranspiring field by a passing cloud blocking the sun, ET would continue for a very short moment (seconds to minutes) at nearly the same rate, but with part of the energy supplied by the sun for evaporation now coming from the heat stored in the crop and soil. The loss of the stored heat to the evaporation process reduces the temperature of the crop and the soil. The cooler temperature then leads to a lower water vapor concentration in the crop and at the soil surface, which in turn slows down ET quickly after the cloud blocks the sun. If the energy supply is suddenly increased as the cloud moves away and the sun reappears, or by a warm wind, ET would remain momentarily at near the original rate, until the extra energy heats up the crop and soil. The higher temperature then raises the water vapor concentration in the leaves and at the soil surface, leading to an increase in ET.

Water vapor concentration in leaves and at the soil surface change with temperature because saturation water vapor concentration is strongly dependent on temperature, rising as temperature of the water increases (Clausius-Clapeyron equation). The air space network inside leaves is essentially saturated with water vapor. For any given soil water status (soil moisture tension), the air layer a few molecules thick adjacent to the soil is also nearly saturated with water vapor. Hence, changes in temperature of the leaves and the soil are associated with changes in water vapor concentration at the water losing surface.

Under favorable conditions with ample water supply when leaves are photosynthesizing at a high rate, stomata of most crop species are essentially fully open. In that case the foliage canopy acts essentially as a fully wet surface, transpiring at a rate similar to evaporation from a free body of water at the same temperature, covering the same land area as the canopy, and under the same aerial environment. This rate may be loosely referred to as the potential rate of transpiration, evaporation, or evapotranspiration. When plants are deficient in water or nutrients, and when temperature is too cold, stomata are less open and photosynthesis rate lower, the canopy would act as a surface that is less than fully wet, and transpiration would be below the potential rate. For the soil, evaporation is at the potential rate when the surface is fully wet and vapor concentration essentially the same as that of a body of water at the same temperature. When the soil surface begins to dry out and surface vapor concentration falls significantly below that of free water at the same temperature, soil E would fall below the potential rate.

Crop fields may be considered to be composed of three types of surfaces-canopy surface, exposed soil surface, and shaded and sheltered soil surface. Shaded soil surface receives very little radiation and is at a temperature considerably lower than that of exposed soil. This, coupled with the fact that it is generally subjected to less wind and under air of higher humidity because of transpiration of the canopy overhead,

limit its evaporation to a very low level. Consequently, one may assume that ET from a crop field is largely due to T from the canopy and E from the exposed soil surface. For situations of fully wet exposed soil surface and canopy with fully open stomata, the field acts as a fully wet surface as a whole, and evapotranspires at essentially the potential rate or slightly higher. For situations of partial canopy coverage of the soil combined with dry or not fully wet exposed soil, the field would evapotranspire at a rate lower than the potential and acts effectively as a surface that has dried to some degree.

Reference ET and Crop Coefficient

When the surface is fully wet, ET is at the potential rate determined by atmospheric conditions. The important weather variables are radiation, temperature, water vapor concentration (humidity) in the air, and wind velocity. An integrated measure of the capability of the atmosphere to supply the energy for ET and carry away the water vapor is reference evapotranspiration (ET_0). ET_0 is defined as “the rate of ET from an extended surface of a short green crop (usually a grass kept short by frequent mowing), completely shading the ground and not short of water or nutrients”. For practical purposes, ET_0 is either the same or very similar to potential ET and may assumed to be the same. Instead of being measured on grasses, ET_0 is now commonly calculated from weather data using certain formula, or derived from pan evaporation data. Sufficient research has been done previously to verify that the calculated results are in close agreement with the results measured on grass as a reference crop (Doorenbos and Pruitt, 1975). For different locations in California, the Department of Water Resources collects the weather data from a network of weather stations and makes the ET_0 data available for downloading from its web site. Although defined with grass as a reference crop, ET_0 takes into account the effects of weather and is indicative of the evaporative demand of the atmosphere. The influence exerted by the crop and the soil on ET, however, is not included in ET_0 . Crop and soil exert their control on ET mostly by altering the wetness of their surfaces. To a minor degree the roughness of the field, mostly determined by geometry of the vegetation, also exerts an effect. A rougher surface causes air moving over it to be more turbulent, enhancing the rate of ET slightly. In the common practical method of estimating ET, the impact of the crop and the soil is accounted for by a coefficient known as crop coefficient (K_c). K_c is defined as the ratio of crop ET to ET_0 , such that:

$$ET = K_c ET_0$$

Thus, K_c is essentially an integrated measure of the “effective wetness” and roughness of the surface of the field, while ET_0 is an integrated measure of the evaporative demand of the atmosphere. Another way to consider K_c is to think of it as ET of the crop normalized for the evaporative demand of the atmosphere. The simple equation holds for different time intervals chosen, ranging from hourly ET to weekly and monthly means.

Seasonal Pattern of ET of Annual Crops

The life cycle of annual crops may be divided into three phases, each characterized by its own ET rate and somewhat different response to environmental or management factors. During the first phase, the foliage canopy, very sparse at the beginning, grows with time until it fully or nearly fully covers the soil. The second phase, usually lasting for several weeks or more, consists of the time period when the canopy is full and green with no obvious yellowing. This is the period when the crop produces dry matter at the highest rate due to high rates of photosynthesis per unit of land area. The third phase starts as the crop begins to mature and the older leaves senesce and turn yellow first, followed by younger and younger leaves, until the crop is fully mature or harvested.

An example of the pattern of ET of an annual crop over the first two phases plus the beginning of the third phase is given in Figure 1. ET_o calculated from weather data is depicted by the dashed line. Effects of day-to-day variations in weather on ET are discernible as indicated by the variations in ET_o . More importantly, features attributable to the development of crop canopy cover and changes soil surface wetness stand out in Figure 1. For the first half of the graph, there is a gradual rise in base-line ET that can be visualized if one draws an imaginary smooth curve connecting the lowest ET rates for the first half of the graph. Added to this base line are several skewed ET peaks occurring after each irrigation. The peaks (referred to simply as irrigation spikes) are due to evaporation from the exposed soil surface after it is wetted by the irrigation water. As the soil surface begins to dry one or two days after an irrigation, soil E declines with time. The basal ET is due mostly to transpiration from the crop, plus some residual evaporation from the exposed soil at its driest point. In the first two or three weeks after planting, the plants have only very few leaves and the canopy covers only an insignificant portion of the ground. Therefore soil E accounts for virtually all of the ET. As the canopy of the crop develops, more and more of the ground is covered by the canopy, which continues to transpire regardless of the wetness of the soil surface, as long as the crop is obtaining sufficient water from the deeper part of the soil to keep its stomata open. Hence, base line ET rises with time in Figure 1, until the canopy covers the ground nearly fully.

With full ground cover, the canopy intercepts nearly all the radiation energy and accounts for most of the ET and soil E is not of much significance. ET is then insensitive to the wetting of the soil surface under the canopy, and hence is not affected perceptively by irrigation. In Fig. 1, the soil was mostly covered by the crop canopy about 55 days after planting. There were therefore no marked irrigation spikes in ET after that time, in spite of the irrigations. Near the end of the time interval shown in Fig. 1, older leaves of the canopy begin to turn yellow. This senescence apparently accounted for the decline in ET relative to ET_o at that time. The dip in ET on days 54, 66, 74, and 75 after planting were the result of cloudy and cool weather as indicated by the low values of ET_o on those days.

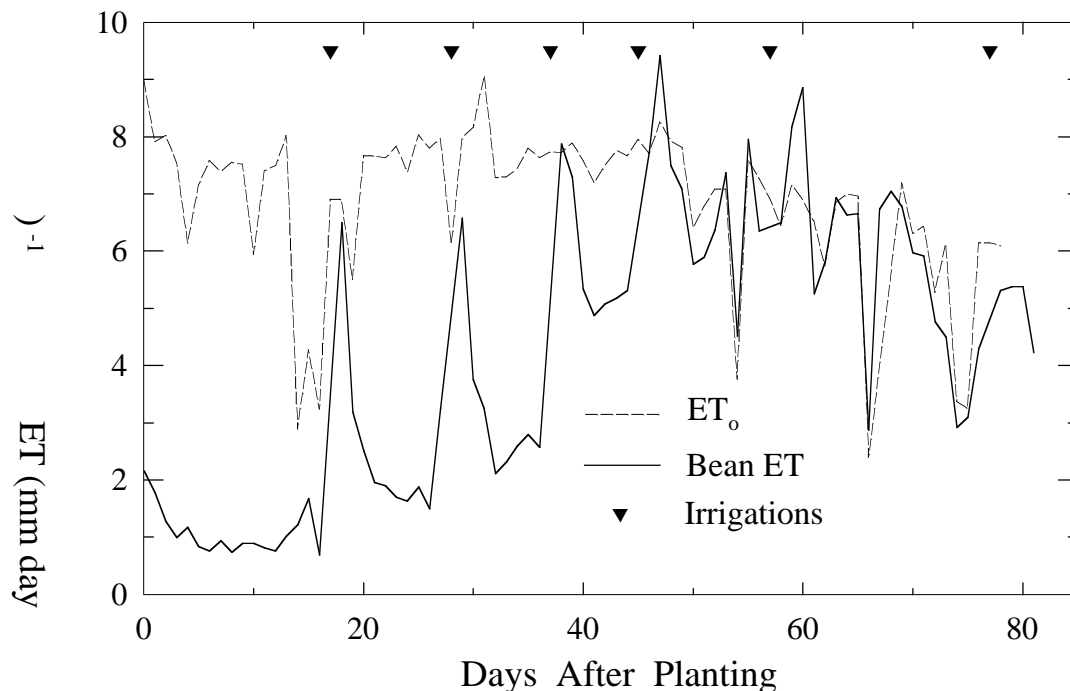


Figure 1. Daily evapotranspiration from a bean (*Phaseolus vulgaris*) crop planted at a density of 19 plants m^{-2} in rows 76 cm apart and measured on a 6.1 M diameter lysimeter. Also given is reference evapotranspiration (ET_0) provided by the nearby CIMIS weather station, at Davis, California. Summer, 1982. Inverted triangles indicate the days of sprinkler irrigation. Reproduced from Hsiao (1990).

In terms of K_c , it is easily deduced from Fig. 1 that early in the season, K_c is close to 1.0 only right after each irrigation because ET is close to ET_0 only then. Right after an irrigation the exposed soil surface is wet, and the canopy as usual, acts as a wet surface. Afterwards K_c falls rapidly below 1.0 as ET falls rapidly below ET_0 because the effective wetness of the overall surface is decreasing due to drying of the exposed soil surface. After the canopy covers the ground nearly completely from day 55 onward, the value of K_c is close to 1.0 as ET tracks ET_0 closely. The surface of the field stays fully wet during that time because the crop, fully covering the soil, is well supplied with water and its stomata are fully open. Near the end of the period depicted in Fig. 1, K_c falls below 1.0 as ET falls below ET_0 due to the beginning of senescence of the canopy.

The impact of leaf senescence on canopy ET and K_c is more clearly seen in another study on maize (Steduto and Hsiao, 1998). ET was measured on a dry treatment growing only on water stored in the soil and on a wet treatment (control) that was irrigated regularly. As shown in Fig. 2, due to water deficit the dry treatment senesced earlier; its green leaf area started to decline around 95 DAP, with the LAI falling from a value of 6 to about 1.5 over a period of 20 days. The LAI of the control also fell at about the same rate, but started considerably later, at around 110 DAP. Consequently, K_c declined considerably earlier for the dry treatment than the wet treatment. There is some indication that a part of the difference in K_c is the result of reduced stomatal opening in the dry treatment, but most of the effect is due to leaf senescence induced by water deficit (Steduto and Hsiao, 1998).

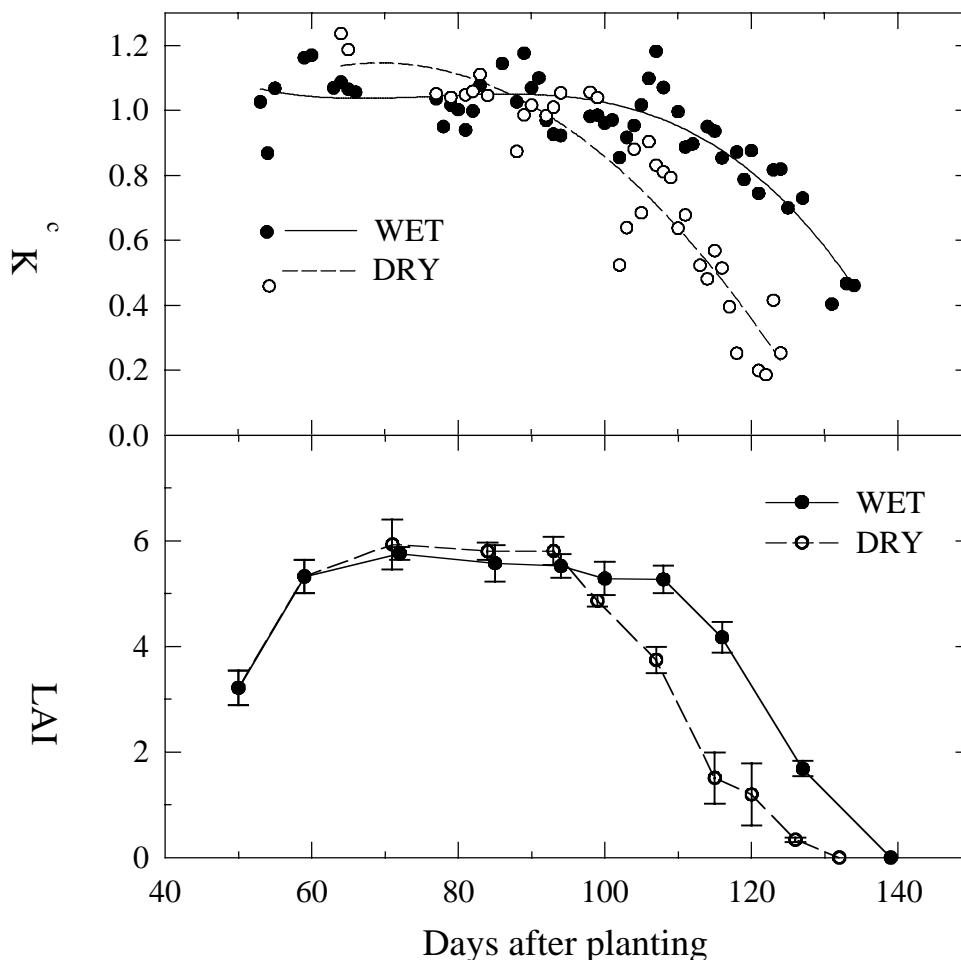


Figure 2. Daily crop coefficient (K_c) calculated as ET/ET_0 from sunrise to sunset and LAI (green leaves only) of corn grown on water stored in the soil (DRY) or with frequent irrigation (WET). ET was measured by the Bowen ratio/energy balance technique. Modified from Steduto and Hsiao (1998).

In contrast to the relatively smooth curves of K_c vs. time one finds in most irrigation books (often in tabulated form), the value of K_c deduced from Fig. 1 varies sharply from day to day for the first half of the figure. To a lesser extent that is also the case for the data in Fig. 2. That is because curves of K_c in books are usually smoothed out to represent the mean value over a long period. It is clear that during the first phase of the life cycle of a crop, K_c would vary with the number of irrigation spikes and area under the spikes and under the base-line ET. These in turn, will depend on the frequency of wetting of exposed soil surface and on the degree of canopy cover. Thus, K_c would be dependent on rainfall events and on the schedule of irrigation, as well as on the starting canopy cover and the rate of canopy development. Starting canopy cover in turn is partly dependent on density of the planting. Since all these items vary from location to location depending on conditions, K_c for the first phase would vary also. Thus, values of K_c for the first phase taken from the literature can only serve as a very rough approximation, and should be adjusted according to location conditions and practices. Similarly, because the starting time and rate of canopy senescence are usually affected by crop nutritional status, water deficit and temperature regimes, K_c for the third phase also can only be taken as approximation and should be adjusted for the time of onset and rate of senescence.

The preceding discussion also makes clear that not only the total ET, but the proportion of soil E making up ET depends too on the frequency of wetting of soil surface and the degree of canopy cover, and hence, should vary with local conditions and practices. At the same time, the discussion points to some possible options to reduce the E portion of ET, a topic to be taken up later. First, it is necessary to know how much of ET is due to soil E and under what conditions.

Measuring or Estimating E and T Separately

A fair number of papers have been published reporting separate estimates of soil E and plant T. Before considering these data and judging their reliability, it is necessary to consider the difficulties involved in making these estimate and review the methods used.

It may appear to be simple to separate out the rate of plant transpiration (T) from soil evaporation (E). In fact it is difficult to do. One important reason is that the plants and the soil share the same energy source and the same or closely overlapping aerial environment; therefore T and E interact. For example, in the case of a partial canopy cover with a substantial portion of the soil surface exposed and wet, soil E would cool the surface soil and the adjacent air, and humidify the adjacent air. Hence, the plants would be cooler and transpiring in a more humid environment, and T would be less compared with the situation when the soil surface is dry. If exposed soil between plants is covered to eliminate E, plant T would increase to some extent because the energy that would have gone to support soil E is now partly available to enhance plant T.

Another cause of the difficulties encountered in separating out T from E is the fact that the water evaporated from the soil or transpired from the plants comes ultimately from the same reservoir in the soil, and the rate of water depletion from this reservoir determines how wet or dry the soil surface would be and its rate of E. If one isolates a portion of the soil in a container to measure E from that portion, there would be no root removal of water from that portion, nor drainage or capillary rise of water from the soil layer below. This will lead in time to a soil surface different in wetness and vapor concentration than that of the non-isolated soil.

Since soil E and T interact, either of them can be measured simply by eliminating the other. Measuring the rate of water loss after removing the plants would overestimate E, and measuring after sealing the soil surface to eliminate soil E would overestimate T. In both cases the measured rates would be higher than the rate taking place with the original spatial pattern of plants on the soil, because eliminating one liquid-to-vapor conversion process would make the air drier and more energy available for the other process. It is necessary to measure one in the presence of the other to obtain realistic values. There are only a few ways to do this directly, and more ways to do it indirectly.

For fields with crops growing soil E is normally measured with microlysimeters, made by filling small (e.g., 1-liter) containers with the soil and burying the containers between crop rows. The weight loss of the microlysimeters over time on an area basis provides a measure of soil E for the field. For the measurement to be reliable, the following conditions must hold: (a) The position of the microlysimeters relative to the plants must be representative of the field. This is normally achieved by placing several lysimeters at equal distance between two plant rows, and replicating the lysimeter arrays at several locations. (b) The surface of the soil in the microlysimeter must be similar to that outside in smoothness and consolidation. This can be achieved by fitting an virtually intact core of soil in the lysimeter, or by

packing disturbed soil inside the lysimeter and letting the soil consolidate over one or more wetting/drying cycles. (c) The soil surface within the lysimeter must be nearly identical in water status as that of the soil adjacent to the lysimeters. This is difficult to achieve if the lysimeter, once installed, is used over a long period, because the soil inside is hydraulically isolated from that outside and roots are not inside the lysimeter to remove the soil water as it occurs outside. This problem can be overcome by installing sets of lysimeters frequently and measuring the weight loss of each set only over a short interval of a day or two. Alternatively, a large number of lysimeters may be installed, watered in a way to obtain a narrow range of surface wetness similar to that of the soil outside, and then measuring the weight loss only of those with wetness of the soil surface matching that outside. Wetness of the surface can be matched by measuring surface temperature with an infrared thermometer and choosing only lysimeters with surface temperature nearly identical to that of the soil outside under similar canopy shading. Unfortunately, to our knowledge this promising method, although alluded to in a publication (Walker, 1984), has rarely been applied to making measurement of soil E. Another way to ensure the match is to measure vapor pressure of the soil surface inside the lysimeters with the instrument of Seymour and Hsiao (1984).

Soil E has also been estimated from measured changes in water content of shallow layers of surface soil over time. This procedure is fraught with problems because water content may be changed by root water removal and vertical water movement within the soil, in addition to surface evaporation. Ritchie and Burnett (1971) ameliorated a part of this problem by relating lysimeter measured bare soil E rate to surface (3 cm layer) soil water content and using the relationship to deduce soil E from measured surface soil water content. This does not, however, take care of the root water removal problem. Another way to estimate soil E is to apply the Bowen ratio/energy balance (BREB) approach to measure the upward latent heat flux in the air very close to the surface of the soil between widely spaced crop rows (Ashktorab et al., 1994). Though novel, the estimates are likely confounded since gradients of temperature and humidity in the horizontal direction are probably marked and the normal fetch requirement for using the BREB technique is not met.

As for transpiration, T of single plants is now estimated by measuring the rate of upward flow of water in the plant stem. The assumption is that this rate is equal to the rate of T , a good assumption when measuring over a 24-hour period. When the measurement covers shorter periods (e.g., hourly), the results can be quite inaccurate because there is usually a substantial lag in the upward water flow behind transpiration in the morning, and in the transpiration behind the upward flow in the afternoon. The technique relies on the fact that applied heat would be carried by flowing water. By applying heat to the basal part of the stem, water flow is inferred from heat flow based on temperature measurements. The simpler method is to determine the rate of heat pulse traveling up the stem by applying pulses of heat at the base and determining the time it takes for the change in temperature to reach a measured distance up the stem from the point of heat application. The measurement yields the velocity of water flow. To obtain the flow rate or quantity of water flow per unit of time, the measurements have to be calibrated against measured rate of transpiration. The method is inaccurate because due to differences in xylem geometry and blockage from plants to plants, the calibration obtained from one plant may not be applicable to another. A better way is based on balancing the heat input to the stem against the heat outflow, yielding directly the rate of flow. The base of the stem is wrapped in an electrical strip heater and the heat input measured in watts. Thermal couples are placed to measure the temperature gradients up and down stream from the heater, and radially across the insulation wrapped outside of the heater. These data, together with thermal conductivity of plant stem and of the heater insulation, are used to calculate with heat transport

equations the heat lost by thermal conduction. The difference between the heat input and loss by thermal conduction indicates the amount of heat transported away from the heater by water flow in the stem. Water flow is then computed from the heat capacity of water and the temperature data.

For the stem flow to be indicative of T of the field, a relatively large number of representative plants must be measured simultaneously. This can be expensive if commercial stem flow gauges are used, especially if the measurement is over many days when stems of the plants are enlarging, necessitating changing over from gauges of one size to gauges of progressively larger sizes.

Soil E and canopy T can also be estimated indirectly. An early method is to sample plants for dry weight and measure ET periodically as the plants grow, and then plot the dry matter produced versus the cumulative ET . Usually the relationship is linear and the line intercepts the ET -axis at a value considerably higher than zero. This intercept value is taken as the total amount of soil E . The underlying assumption is that the amount of dry matter produced at different growth stages of the plant is proportional to the cumulative amount of water transpired up to that time, a fairly reasonable assumption (Fischer and Turner, 1978). Plant T is then the difference between soil E and total ET .

The most obvious indirect way to estimate soil E and canopy T separately is by model simulation. The models are some times very simple but inaccurate. For example, by assuming that soil E declines linearly with time after a soil wetting. More complicated models estimate advective transfer of energy and water vapor between the soil and the canopy environ (e.g., Shuttleworth and Wallace, 1985), but require either simplification of fundamentally complex situations or parameterization for different conditions.

Still another way to estimate canopy T indirectly is to calculate it from measured leaf conductance and leaf area. This involves much uncertainty because the scaling up process, from the leaf level to canopy level, is still experimental and not yet well worked out.

Magnitude of Soil E Relative to ET as Reported in the Literature

In the published studies, soil E was reported to range from a few percent to as much as over 80 percent of the measured or estimated ET . Because of the difficulties encountered in measuring or estimating E and T separately, there is considerable uncertainty in some of the reported results. Nonetheless, some firm data from several studies, together with the relatively consistent conclusions drawn in many other studies of less definitive nature, permit a fairly quantitative assessment. These studies are examined in some detail here, starting with the cases where soil E constituted the major portion of ET and ending with situations where soil E is minimal.

As expected from the previous discussion on factors affecting soil E and plant T , high ratios of E to ET are observed mostly when canopy cover or LAI (leaf area index, leaf area per unit land area) of crop is low and the soil surface is wet or at least not very dry much of the time. Examples are the results obtained by several groups when soil E was measured with microlysimeters under sparse canopies just a day or two after soil surface was wetted. Lascano et al. (1987) found soil E for a cotton field under a LAI of 1.0 to be slightly higher than 5 mm per day on days when ET_0 should be in the range of 7 mm per day as judged by the level of solar radiation. Villalobos and Fereres (1990) measured soil E to be 60-80 percent of ET_0 for sunflower, maize and cotton with LAI of 0.6 to 1.2. For longer terms but with parts of soil surface drying intermittently, Sadras et al. (1991) found soil E , measured by microlysimeters installed freshly each week, to be 50 percent of ET for two cultivars of sunflowers over a period of 64 days starting

33 days after crop emergence. The plants were spaced widely apart with LAI reaching a maximum of only 1.4 in one cultivar, and 0.9 in the other. Hence, a high proportion of the soil remained exposed for the whole season. The crops were drip-irrigated with 23 to 42 mm of water per week, and there were two rains, of 12 and 8 mm. Presumably a substantial fraction of the soil surface remained wet most of the time. For treatments with irrigation omitted and the soil surface allowed to dry out during either the first half or the second half of the test period, soil E for the 64 days was reduced to 30-35 percent of ET.

Similarly high proportion of soil E was also reported by Lascano and Baumhardt (1996). They used the ENWATBAL model to assess dryland cotton during a period when the LAI started at 0.5-0.9 and reached 1.9 later. There was one furrow irrigation of 100 mm at the beginning of the assessment period and some nine rainfall events totaling 225mm. The simulation daily soil E over a 7-day period after the irrigation was in good agreement with the results measured by microlysimeters (Lascano et al., 1994). For the whole assessment period of 90 days, the simulated soil E was 50 percent of ET.

As the crop canopy covers a greater and greater portion of the ground, soil E becomes less and less. With the exception of crops planted in very widely spaced (e.g., 60 inches or 1.5 m) rows, canopy cover is usually nearly complete (e.g., 95 percent percent) when LAI is 4.5 or higher. In such situations, soil E constitutes a minor portion of ET, even when the soil surface is fully wet. Adams et al. (1976) and Arkin et al. (1974) used arrays of evaporation plates covered with a thin layer of soil to measure soil E after sprinkler irrigations. E of fully wet soil surface as a fraction of ET declined as LAI increased and shading of the soil increased. When the soil was nearly fully shaded, soil E was still 18 percent of the potential value. Jara et al. (1998) combined extensive measurements of T with stem flow gauges, soil E with microlysimeters, and total ET with BREB technique to assess the extent of soil E for maize irrigated by furrow six times during a 64-day period when LAI increased from 3 to 5.2 and then decreased to 4.5. They found daytime soil E, measured by microlysimeters and averaged for 28 days of observation that included up to 6 days after each irrigation, constituted 13.6 percent of daytime ET. But soil E calculated as the difference between ET and T measured by stem flow, averaged over 40 days and including days later than 6 days after an irrigation when the soil surface was drier, constituted only 9 percent of the daytime ET. Although this difference may not all be due to differing soil surface wetness, the data nonetheless show that E was a fairly small fraction of ET when LAI was high. This conclusion is also supported by the results of Bethenod et al. (2000), who studied maize over a 17-day period one year, and a 46-day period the next year. During the study periods, canopy cover of the soil was complete with a LAI of around 4.0. Rainfall, mostly light, was frequent, with the longest dry period being 16 days, and the next longest, 6 days. Overall, the data showed that if soil E was taken as the difference between ET measured by the BREB technique and T measured by stem flow gauges, soil E was approximately 10 percent of the ET.

The higher proportion of soil E under high LAI or canopy cover measured by Arkin et al. (1974) and Adams et al. (1976) in comparison with that measured with microlysimeters and stem flow gauges (Jara et al., 1998; Bethenod et al., 2000) may partly be attributed to the fact that the surface of the evaporation plate used in the former case remained fully wet all the time, whereas in the latter case the soil surface dried out at least to some extent between wettings by rain or irrigation. There might also have been some systematic differences caused by the use of different techniques. Nonetheless, it appears safe to conclude that when canopy cover of the ground is essentially complete, soil E may constitute 10 or 15 percent of ET under normal weather or irrigation conditions with periodic drying of the soil surface, and somewhat more if the soil surface remains fully wet all the time.

Over the full range of canopy cover or LAI, it is desirable to have a function (curve) relating soil E to the LAI or percent of canopy cover. In the literature a number of empirical curves have been constructed from experimental data. Four of them are presented here in Fig. 3. It is seen that generally the curves deviate from each other. The only consistency is that they all show soil E relative to ET or ET_o to decline exponentially with increase in canopy cover or LAI. In considering these curves, it is important to note a number of uncertainties. For one, the soil surface condition may not be as well defined as desired. For example, in the case of Curve (d) obtained by Ritchie and Burnett (1971), soil surface is assumed to be fully wet but in fact could be partially dry because stage 2 evaporation was taken to start after 10 mm of water has evaporated since wetting of the soil whereas their Figure 3 showed stage 2 already started after only 5 mm of water has evaporated. The second uncertainty is that in the case of the relationship with LAI, it will depend on the geometry of plant distribution. The more uniformly the plants are distributed on the land, the more effectively they would shade the soil and reduce soil E. As already mentioned, wide spacing between rows with plants densely spaced along the row will require a higher LAI to shade the same proportion of soil as compared to more narrow distance between rows with plants less densely spaced along the row. Another caveat is that the values are estimates in the case of Curve (d). It was assumed that soil E was equivalent in energy terms to the net radiation measured below canopy when soil surface is wet (Ritchie and Burnett, 1971).

Experimental Studies

As a part of the effort to assess the extent of E relative to ET, to quantify better crop ET and consumptive water use, and to better define the conditions that affect ET, several field studies were carried out in 1999 and 2000 supported by funds from DWR. These studies and the results are described by topics below.

ET of Crops at Two Plant Densities-Indirect Assessment of Soil E

Growing plants at a higher density results in a faster foliage canopy development and more coverage of the soil in the early part of the season. As already discussed, this would reduce the proportion of ET lost by soil evaporation and increase the proportion lost by plant transpiration. Detailed data on ET as affected by plant density are rare. This part of the project is to develop more such data and to assess how much of the soil E may be saved by planting at higher densities.

Methods

The two large (6.1 m diameter) lysimeters at the experimental field of the University of California, Davis were planted on June 4, 1999 with cotton, at a density of 25 plants per m^2 for the weighing lysimeter (WL), and 8 plants per m^2 for the floating lysimeter (FL). The two lysimeters have essentially the same sensitivity and resolution for measuring ET.

A large area surrounding the lysimeters was also planted with cotton of similar density at the same time, to provide adequate fetch or upwind guard area. The lysimeters were routinely irrigated by filling the furrows between beds with water at the time when the surrounding field was furrow-irrigated. However, early in the season the work on the extent ET is suppressed during sprinkler irrigation (see a later section) was also conducted on the lysimeters, entailing the application of water by sprinklers on a number of days. Canopy coverage of the soil was measured periodically by the light interception method with a 1-m long light sensor. ET was monitored over the season by measuring changes in the lysimeter output voltage, calibrated as changes in weight and converted to changes in water content per unit land area. A data logger scanned the output every 1 second, and calculated and stored the mean for each 5 min

interval. The data were downloaded to a computer, adjusted or corrected for the occasional resetting of the sensing mechanism, perturbations caused by persons walking on the lysimeters to take measurements, and irrigations. Daily ET rate was obtained from the adjusted data by summing the 5-min means.

Results and Discussion

The patterns of daily ET for the two densities over the season are presented in Fig. 4, with each sprinkler irrigation (associated with the work of a later section) denoted by an open triangle, and furrow irrigation, by a closed inverted triangle. Also presented in the same figure are the data on canopy cover. Early in the season when the canopy cover was small, each irrigation caused a large increase in ET (irrigation spike) because of wetting of the exposed soil surface. As the soil surface dried over time, soil E decreased fairly rapidly and hence ET also. Later in the season when the canopy covered more of the soil surface, irrigation did not cause sharp increases in ET, and the variation in ET from day to day was caused instead by variations in weather conditions affecting the evaporative demand, as indicated by the ET_o curve (Fig.4c).

Canopy cover developed much faster with the high plant density (WL), reaching 80 percent around 60 DAP (Fig. 4a), whereas with the low plant density (FL) 80 percent cover was not reached until the end of the season (Fig. 4b). Early in the season the base line ET (minimal values between the high ET peaks caused by irrigation) may be taken as a very rough approximation of canopy T. Comparing Fig. 4a and 4b this way, one may surmise that E accounted for a higher proportion of ET at the low plant density (FL). The total ET over the 140-day period was 662 mm for the high plant density and 606 mm for the low plant density, a difference of only 9.2 percent. Dry matter production of plants have been shown to be nearly proportional to the cumulative radiation captured by the plant canopy (Ritchie, 1983). Hence, the relative areas under the canopy cover curves are indicative of the relative total amount of dry matter produced at the two plant densities. On that basis, it may be concluded that for an additional consumptive water use of only 9.2 percent, there was a much larger percentage increase in dry matter produced at the high plant density. That is because a larger proportion of the water used went to soil E in the low density planting compared to the high density planting.

For a more clear cut comparison between two plant densities, we refer to some early data collected with the same lysimeters under another research project (Hsiao and Henderson, 1985) funded by DWR. Beans were planted at two densities, 19 plants m^{-2} in rows spaced normally (normal density), 76 cm apart, and 38 plants m^{-2} in narrow rows 38 cm apart (high density). Irrigation was by sprinkler. The daily ET rates of the two densities are presented in Fig. 5, along with the canopy cover data. As can be seen in Fig. 5, ET rate was higher for the high density planting for the first two thirds of the graph, with most obvious difference in the base line ET. The higher base line ET was associated with the faster canopy development of the high density field. This supports the interpretation that when canopy cover is incomplete, base line ET is mostly due to canopy T when irrigation intervals are long enough to permit the drying of exposed soil surface. After most of the soil is covered by the canopy (day 55 onward), there was very little difference in ET between the two densities. The model of Hsiao and Henderson (1985) that calculated E and T separately was used to simulate the ET of the two densities. As shown in Table 1, the simulated soil E for the low density planting was 101 mm or 28 percent of the total ET for the low density, and 44 mm or 11 percent of the total ET for the high density. The simulated results appear to be realistic in that the simulated total ET for the low and high density were, respectively, 362 mm and 406 mm, values surprisingly close to the measured total ET of 358 mm for the normal and 395 mm for the high density.

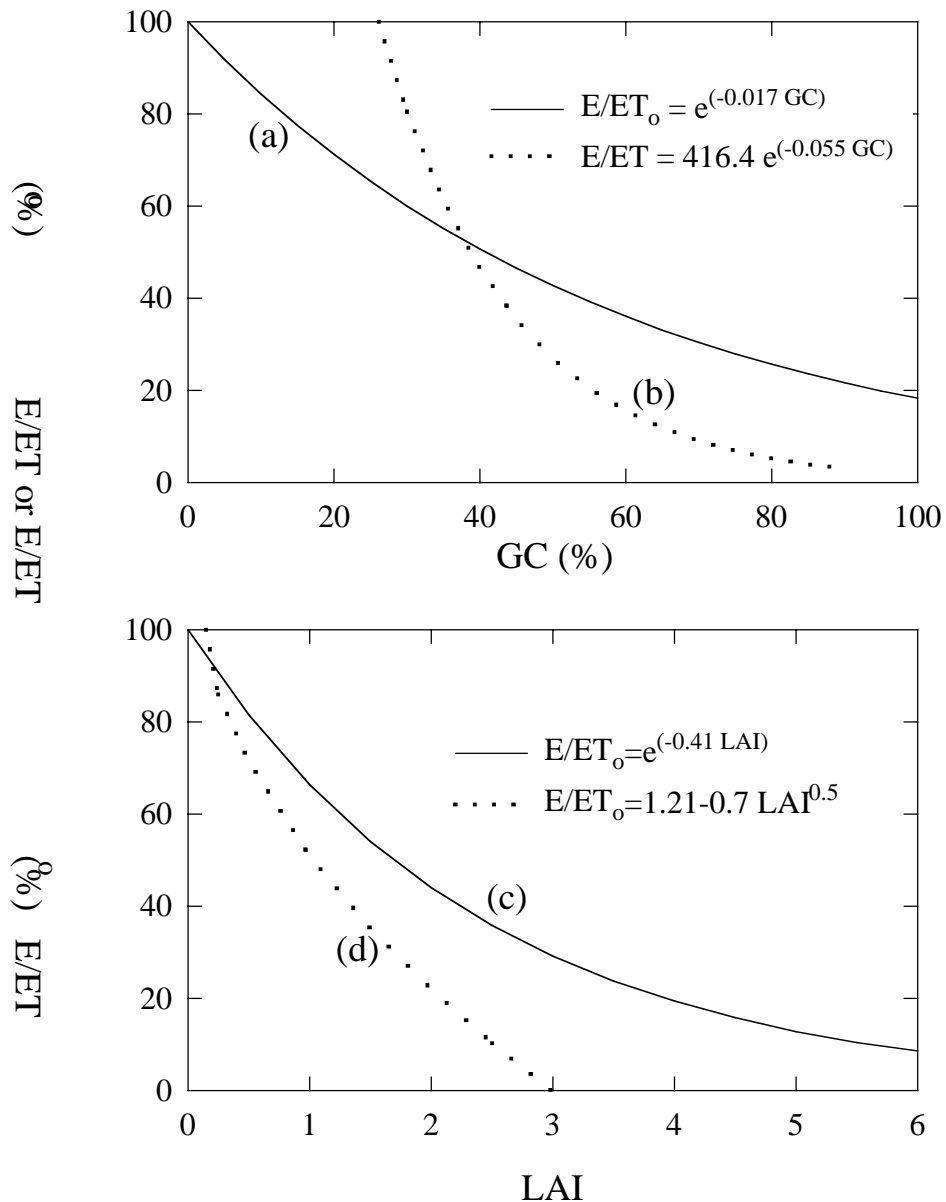


Figure 3. Empirical relationship between ratio of soil E to ET or ET₀ and crop canopy cover or LAI. Equations described by the curves are given in the figure. Curve (a) represents the equation of Adams et al. (1975) fitting their experimental data on sorghum, and the equation of Villalobos and Fereres fitting their data on corn, cotton and sunflower; Curve (b) represents an equation fitting the data of Ashktorab et al. (1994) on tomato; Curve (c) represents the equation of Villalobos and Fereres (1991) fitting their data on corn, cotton and sunflower; and Curve (d) represents an equation derived from the equation of Ritchie and Burnett (1971) for T/ET₀ vs. LAI fitting their data on cotton and sorghum.

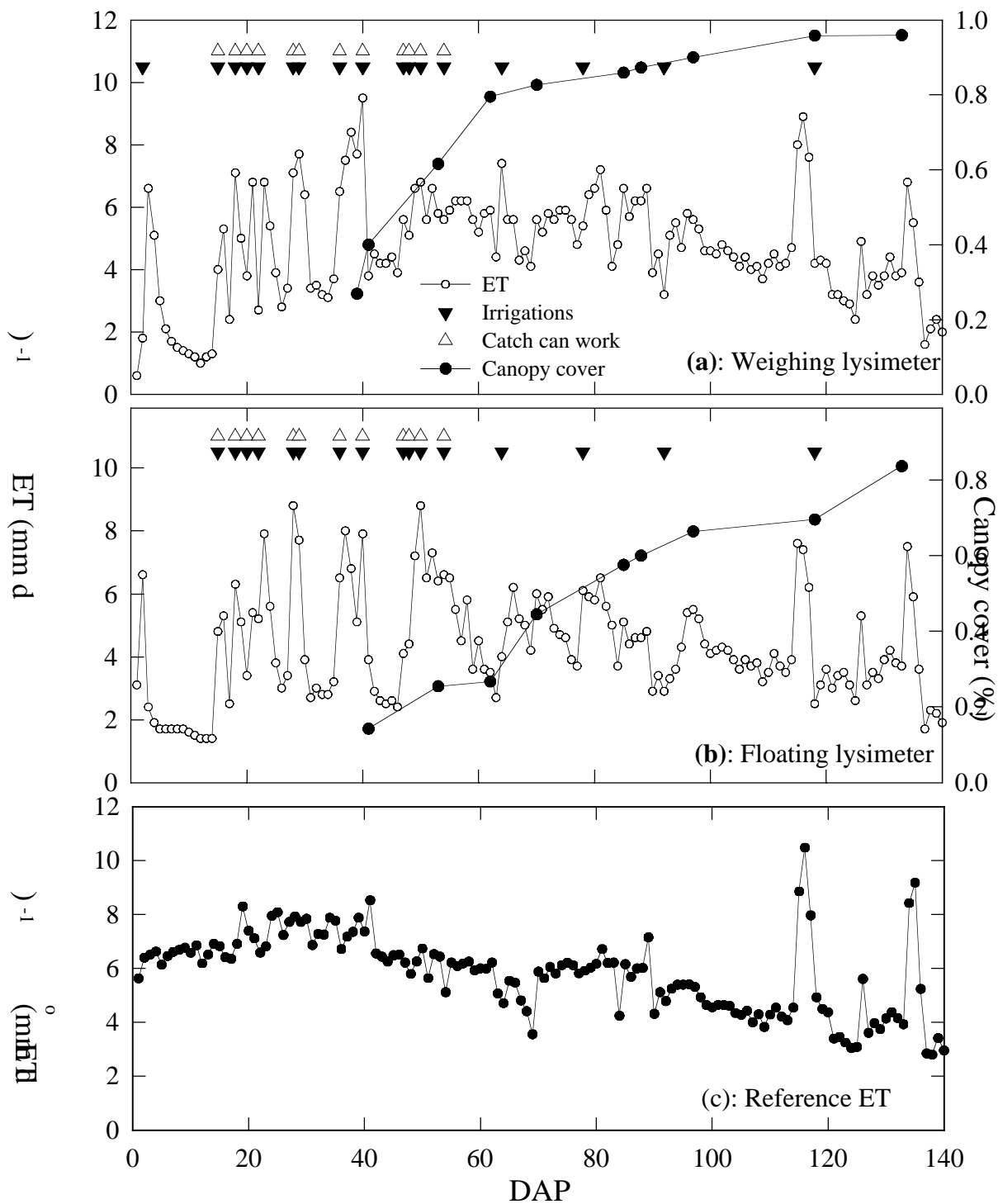


Figure 4. Lysimeter measured ET of cotton planted at two densities, 8 plants m⁻² for the floating lysimeter (b), and 25 plants m⁻² for the weighing lysimeter (a). Percentage of canopy cover and ET₀ provided by the Davis CIMIS weather station nearby are also shown.

A reasonable conclusion would be that the percentage of ET going to soil E can be reduced substantially by narrower row spacing and higher planting density. On the other hand, this would result in a higher total ET because of the increase in canopy T. Higher canopy T, however, is associated with higher productivity, as already discussed.

Comparison of ET Between Drip and Furrow Irrigated Fields

Drip irrigation is often said to save water because only a portion of the soil surface is wetted at each irrigation. While this is likely true for young orchards with trees spaced far apart and most of the soil not shaded, the validity as a general case may be questioned. This study was conducted to obtain more data bearing on this question.

Methods

Cotton was planted on June 13, 2000 in the two Davis lysimeters and surrounding field at the same density. One lysimeter (FL) and adjacent area was irrigated by a surface drip system, and the other and adjacent area, by furrow irrigation. Weight loss by the lysimeters were monitored to calculate ET rate; and canopy cover on each lysimeter was measured periodically. During the early phase of growth, plants on the FL were less green and grew slower than plants on the WL and surrounding area. Tests indicated that the soil of the FL was slightly more saline and basic than the soil of the WL. Extra water was applied at irrigation time the FL to leach the soil and reduce the salinity. The FL plants soon recovered and started to grow normally. To account for the difference in canopy cover, an adjustment in the ET data was made. The excessive canopy cover of the WL (in percentage), calculated by subtracting the canopy cover on the FL from that on the WL, was divided by 100 and multiplied by an assumed crop coefficient of 1.1, and the result was added to the measured ET of the FL.

Results and Discussion

The rate of daily ET under drip and furrow irrigation as measured by the lysimeters are given in Fig. 6, along with the data on canopy cover. Because of the salinity problem with the FL, there was a substantial difference in canopy cover between the two irrigation methods in the first part of the season and it was desirable to adjust the ET data for the difference in canopy sizes as described under *methods*. The adjusted ET data are presented in Fig. 6c. It is seen in Fig. 6a and 6c that the most obvious difference in ET between the drip and furrow irrigated lysimeter in the first 50 days is the lack of irrigation spikes in the former and the prominence of irrigation spikes in the latter. In addition, not as obvious but still clear is the higher ET of the drip irrigated lysimeter starting several days after one furrow irrigation and lasting until the next furrow irrigation. These differences are the result of fundamental differences in the two water application methods. With furrow irrigation, the spikes and the rapid decline are caused by the sudden wetting of the whole soil surface, followed by surface drying and stage 2 exponentially declining evaporation rate from exposed soil surface. With drip irrigation, only a portion of the exposed soil surface is wetted at each irrigation but this portion stays fully or fairly wet most of the time due to the short time intervals between irrigations. Hence, during the time when the furrow irrigated soil surface had dried out enough to limit soil E markedly, the ET of furrow irrigated lysimeter is less than the ET of the drip irrigated one because the latter has a part of its soil surface still wet.

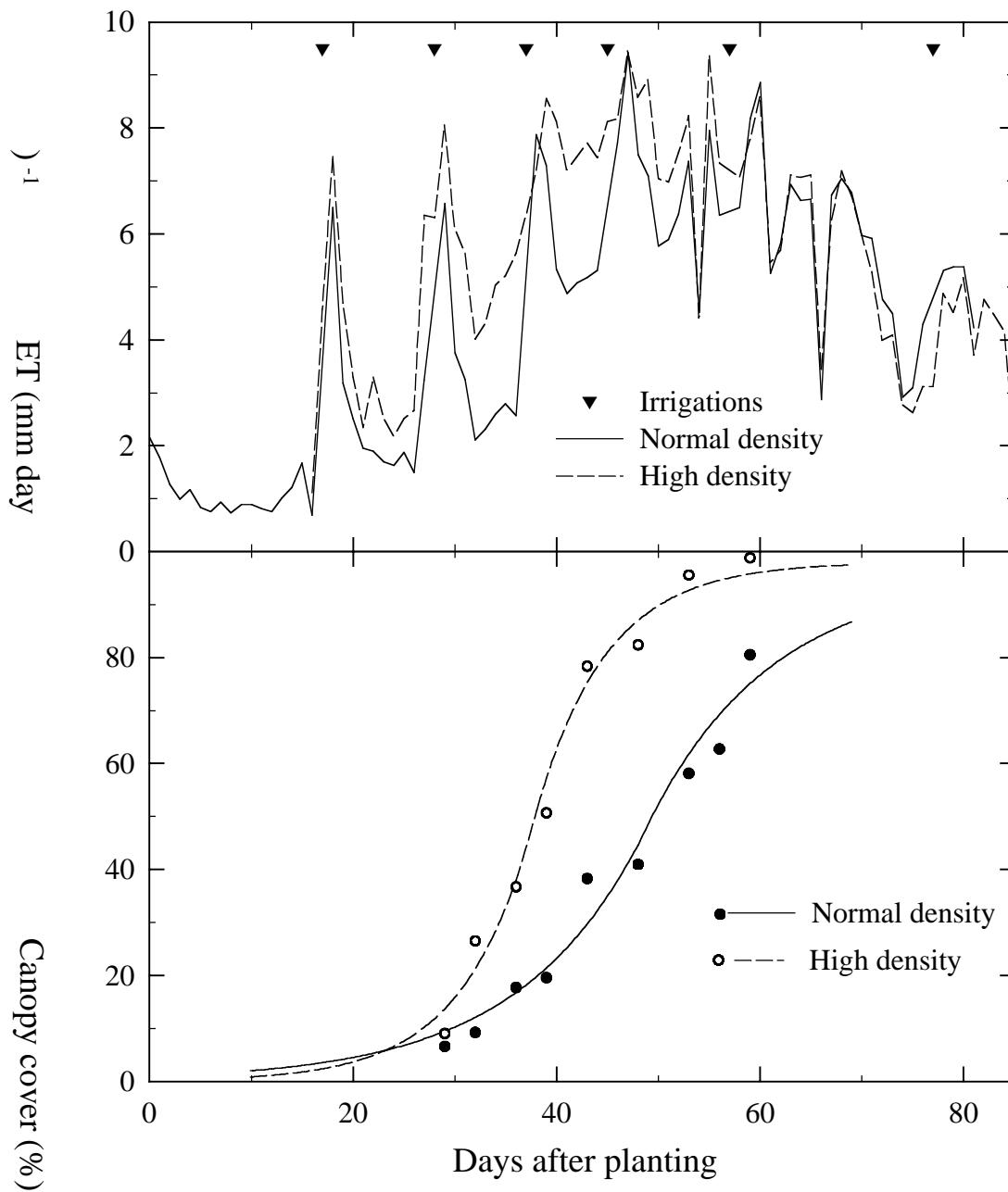


Figure 5. Evapotranspiration and canopy cover of bean planted at two densities, 19 plants m^{-2} (normal, with 76 cm row spacing) and 38 plant m^{-2} (high, with 38 cm row spacing). Inverted solid triangles indicate sprinkler irrigations. Measured canopy cover is given as circles; lines are fitted using the canopy growth model of Hsiao and Henderson (1985). Same experiment as that shown in Fig. 1.

Table 1. Cumulative soil E and canopy T and ET as predicted by the model of Hsiao and Henderson (1985) in comparison with cumulative ET as measured by lysimeters, for fields of beans planted at two different densities. Data are for a period of 79 days starting 1 day after planting.

| | Plant Density | | | |
|---------------|---------------------------|-----------|---------------------------|-----------|
| | 19 plants m ⁻² | | 38 plants m ⁻² | |
| | (mm) | (% of ET) | (mm) | (% of ET) |
| | Model | | | |
| <u>Soil E</u> | 101 | 28 | 44 | 11 |
| <u>Crop T</u> | 261 | 72 | 362 | 89 |
| <u>ET</u> | 362 | 100 | 406 | 100 |
| | Measurement | | | |
| <u>ET</u> | 358 | ---- | 395 | ---- |

Over the period of 90 some days, the measured total ET was 436 mm for the furrow irrigated (WL), and 387 mm for the drip irrigated (FL). After adjusting for the difference in canopy cover (see *Methods*), the total ET for the drip irrigated was 426 mm. Assuming the adjustment is reasonable, the similarity in total ET between the furrow and drip irrigated cotton indicates that drip irrigation does not necessarily save water in some situations. This conclusion is consistent with those drawn in several other careful studies (e.g., Tarantino et al., 1982). In the current study, the frequent wetting of a part of the soil by drip irrigation kept the ET high during the periods when ET of furrow irrigated treatment was low due to soil surface drying over the long intervals between irrigations.

Extent crop ET is Suppressed During Sprinkler Irrigation.

Sprinkler irrigation is sometimes said to be wasteful because after being emitted by the sprinklers, the water drops evaporate partly in the air before reaching the soil and the crop. In terms of the energy balance principle, however, in-air evaporation from the water drops should reduce the energy supply to the field and cool and humidify the air, leading to reduced rate of ET from the soil and the crop. This study was conducted to quantify the extent surface ET is suppressed during sprinkler irrigation.

Methods

The two lysimeters were planted with cotton in 1999 and 2000. To determine the extent ET is suppressed, the normal rate of ET (control) without sprinkling must be known, and one lysimeter (FL) was used for this purpose. The other lysimeter (WL) was used to determine the ET rate under sprinkler application. To measure ET from the soil/crop surface during sprinkler application, the amount of water applied and reaching the surface must be accurately measured and deducted from the change in weight of the lysimeter. Sixty small platforms each with three supporting legs were distributed on the lysimeter. A catch can was placed on each platform and carefully leveled with a spirit level. A layer of oil about 1 cm thick was added to the can to prevent evaporation of water caught in the can. The can with its content was weighed before and after the sprinkler application, to 0.1 g accuracy, to determined the depth of water applied. Tests conducted with cans containing water dyed brightly red and placed on white paper sheets showed that there was no detectable splatter from the can during sprinkling. After adding water to cans containing oil, weight of the cans did not change significantly after sitting in the field for a number of hours, indicating no evaporative loss. For each test run, the FL was irrigated by sprinkler to ensure that its top soil layer is fully wet. The irrigation was stopped just before applying water to the WL (equipped with

catch cans) by sprinklers. The reported rate of ET measured by the WL has been corrected for the surface area occupied by the non-evaporating catch cans.

Results and Discussion

Figure 7 shows an example of the change in weight of the two lysimeters with time during the test. The continuous gain in weight for FL between 11:20 and 14:00 was the result of water application by sprinklers. After the application was stopped, the continuous loss in weight of FL with time was due to ET. At about 14:05 the sprinklers were turned on to apply water to the WL, which gained weight continuously until the application stopped at 16:30. The water applied as measured by the catch cans minus the water gained by the lysimeter between 14:05 and 16:30 was taken as the cumulative ET from the WL during the sprinkler application.

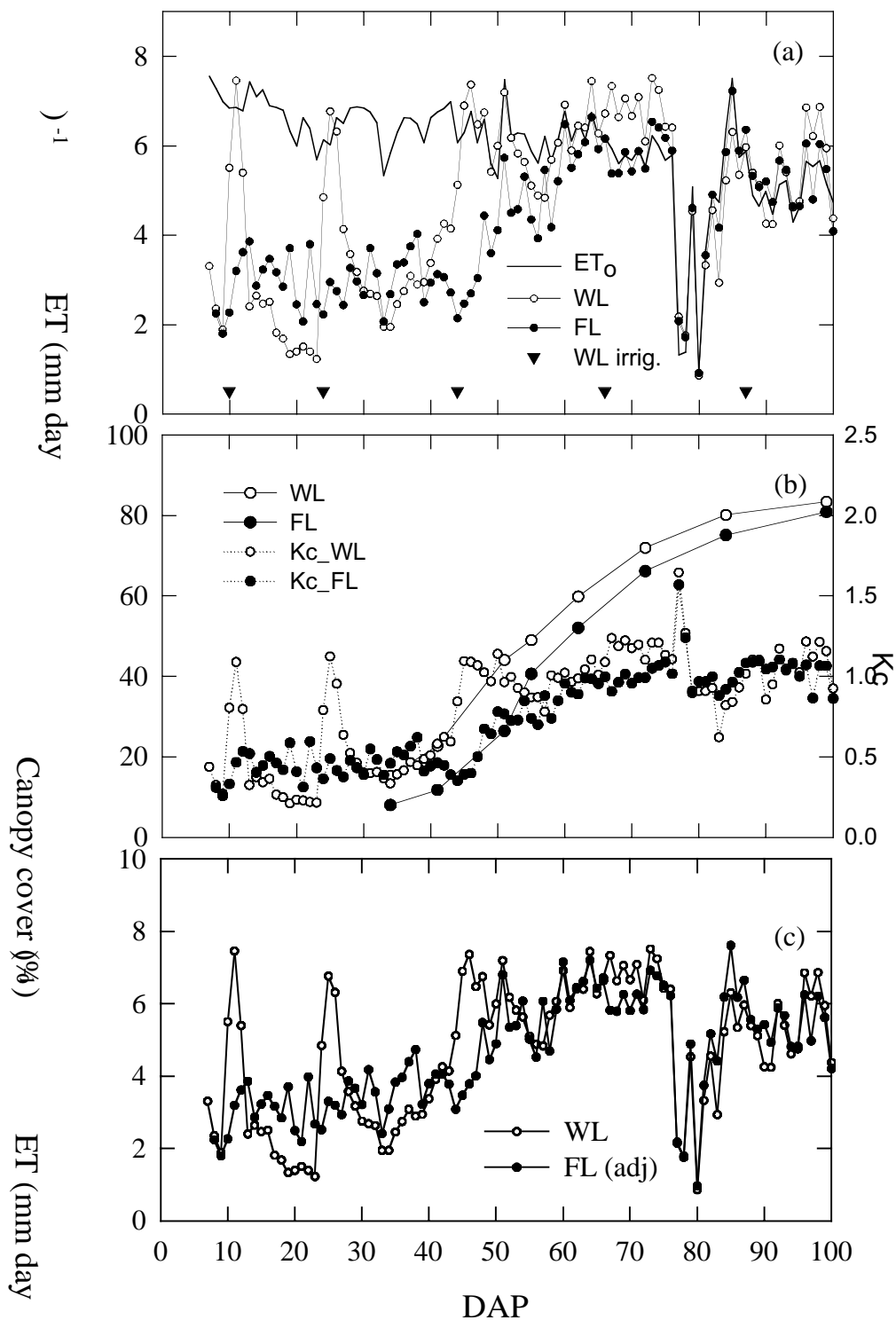


Figure 6. Trend of daily ET, ET₀, canopy cover, and daily crop coefficient (K_c) for cotton under drip irrigation (floating lysimeter-FL) or furrow irrigation (weighing lysimeter-WL). Comparison of crop ET for the two irrigation methods after adjusting for the effect of the lower canopy of the drip irrigated (see *Methods*) is given in (c). Downward triangles indicate the time of furrow irrigation. Planting was on June 13, 2000.

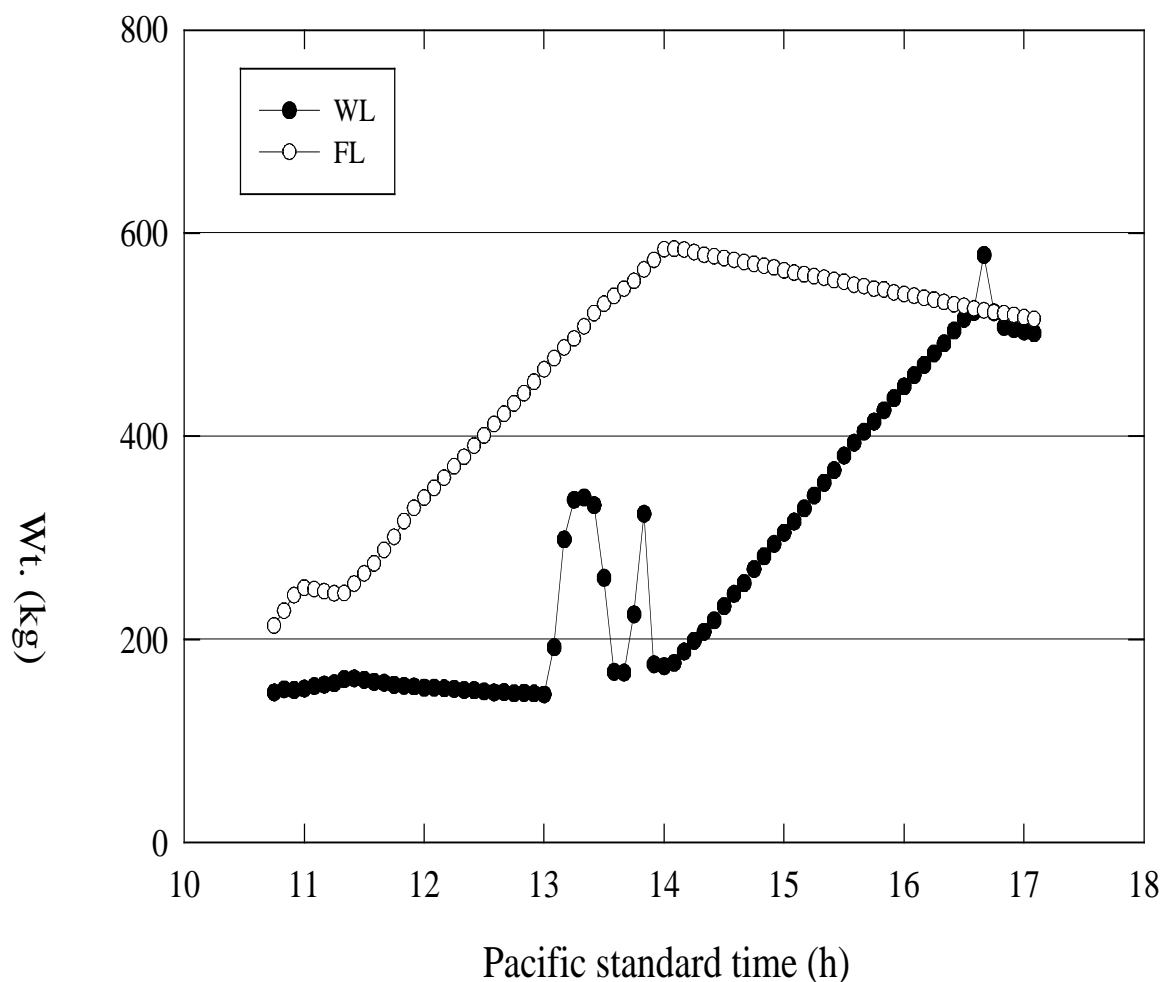


Figure 7. Example of weight change of the weighing and floating lysimeters during the determination of surface ET while under sprinkler irrigation. Weight was measured from an arbitrary reference point and was not the total weight of the lysimeter. The rapid changes in weight between 13:00 and 14:00 were due to weight of the researchers setting up the catch cans, and around 16:45, weight of the researcher taking away the cans for weighing.

Of the total eight tests conducted in 1999, three of them gave unacceptable values of ET under sprinkler irrigation, either much higher than the control ET and ET_0 , or negative values. The results of the remaining five tests and the four tests conducted in 2000 the mean values are presented in Table 2. As can be seen, the variation from test to test was large and less definitive than we had hoped for. It can be seen from the slopes of the lines in Fig. 7 and in Table 2 that ET during sprinkler application is very small relative to the application rate, and hence, relatively small errors in the amount of applied water measured by catch cans can lead to a large error in the calculated ET under sprinkling.

The reduction in ET under sprinkling as a percentage of the control ET was calculated for each test and given in Table 2. For the 1999 tests, the mean percentage reduction was 48 percent, and for 2000, the mean was 46 percent. The overall mean reduction was 47 percent for the nine tests in two years. A

reasonable conclusion would be that during water application by impulse sprinklers, surface ET is substantially suppressed, although in-air evaporation of the spraying water drops probably makes up for the difference and more.

Table 2. ET rate of a cotton field under sprinkler irrigation relative to ET rate not under irrigation (control ET). Reduction of ET rate under sprinkling is given as a percentage of the control ET rate. Control lysimeter was irrigated by sprinklers first, then the sprinklers were turned off at the start of the ET measurement. ET rate was calculated as the difference between the water application rate measured by catch cans and the water gain rate measured by lysimeter.

| Date | Time (Pacific standard) | ET _o (mm h ⁻¹) | Lysimeter water gain rate (mm h ⁻¹) | Water appl. rate (mm h ⁻¹) | Control ET (mm h ⁻¹) | ET under sprinkler (mm h ⁻¹) | ET reduction under sprinkler (%) |
|-------------|-------------------------|---------------------------------------|---|--|----------------------------------|--|----------------------------------|
| Year 1999 | | | | | | | |
| 6/18 | 14:00-16:30 | 0.65 | 4.79 | 4.96 | 0.80 | 0.17 | 79 |
| 6/21 | 11:00-14:00 | 0.72 | 4.74 | 5.40 | 0.85 | 0.65 | 24 |
| 7/1 | 12:00-14:30 | 0.82 | 4.92 | 5.48 | 0.93 | 0.56 | 40 |
| 7/2 | 11:00-13:00 | 0.80 | 5.01 | 5.60 | 0.89 | 0.59 | 34 |
| 7/20 | 12:40-15:10 | 0.70 | 5.72 | 6.00 | 0.76 | 0.28 | 63 |
| Year 2000 | | | | | | | |
| 10/3 | 11:00-14:00 | 0.510 | 6.46 | 6.86 | 0.55 | 0.41 | 26 |
| 10/6 | 10:50-13:50 | 0.58 | 6.06 | 6.42 | 0.66 | 0.37 | 44 |
| 10/13 | 10:30-13:30 | 0.38 | 7.05 | 7.10 | 0.37 | 0.051 | 86 |
| 10/19 | 12:00-15:00 | 0.38 | 6.54 | 6.84 | 0.42 | 0.31 | 26 |
| 2 year mean | | | | | | | 47 |

Extent Transpiration May Increase When Soil Evaporation is Minimized

One idea for saving water is to minimize or eliminate soil E while not restricting crop T. During the early part of the life cycle of crops, only a part of the soil is covered by the foliage canopy and soil E is high if the soil surface is wet. If soil E is reduced, less energy is consumed by soil evaporation and air above and near the soil would be less humid and hotter. This in turn causes the canopy to be hotter and surrounding air to be less humid. T would increase as the result of a large humidity gradient (ΔW) from the leaf to the air. Very little work has been done to quantify this effect by experimental measurements. This study was conducted to develop some of the needed information. The objective is to measure the increase in canopy temperature and the reduction in air humidity and use the data to calculate how much T would be raised by the reduction in soil E.

Methods

In a large field of cotton two adjacent plots, 15x15 m each, were demarcated. The plots were irrigated once or twice to establish the plant stand. On day 35 after planting in 1999, and day 44 after planting in 2000, irrigation began to be applied to the WET treatment every 14 to 20 days, while DRY treatment received none. Temperature of 18 mature leaves on top of the canopy in each plot was measured continuously with fine-wire (40 gauge) thermocouples attached on the lower side of the leaf. The thermocouples were checked every morning, and if they fell off the leaf, the readings back to the previous morning were excluded in the calculation of leaf temperature averaged over all the measured leaves. Vapor pressure inside the leaf was calculated from leaf temperature by assuming vapor saturation. This assumption has been shown to be valid by experiments and is used regularly in all published gas exchange studies. Water vapor pressure and temperature of the air 0.1 m above the canopy of each plot were measured with a precision psychrometer (Held et al., 1990), positioned at the center of each plot to avoid edge effects. Voltage outputs from the thermocouples and psychrometers were scanned every 1 second and averaged every 5 min by a data logger, and the means values stored.

The driving force for transpiration, the difference in vapor pressure between inside of the leaf and the bulk air surrounding the canopy (ΔW), was calculated from the calculated vapor pressure inside the leaf and the measured vapor pressure in the bulk air. To assess the impact of reduced soil E on canopy T, we assumed that the stomatal conductance are basically the same for the plants in the WET and DRY plot and the only effects on canopy T are those due to changes in temperature and humidity (vapor pressure), which alter ΔW . Since the rate of transpiration is proportional to ΔW for a given conductance, the increase in canopy T of the DRY plot due to the dry soil surface should be proportional to the increase in ΔW . That is, the percentage increase in T is the same as the percentage increase in ΔW . Using this approach, the increase in canopy T was calculated and added to the estimate T of the WET plot to obtain T of the DRY plot. Canopy T of the WET plot was estimated using our ET model (Hsiao and Henderson, 1985).

Vapor pressure at and temperature of the soil surface at random locations in the plots were measured periodically with a special instrument (Seymour and Hsiao, 1984). Air humidity at about 1 m height was also measured at the same time with the same instrument.

Results and Discussion

In both years soil surface vapor pressure increased markedly after each irrigation, then declined with time and became nearly the same as air vapor pressure after 10 days to 2 weeks. The data obtained in 2000 are given in Fig. 8. Very similar but less complete data (not shown) were obtained in 1999. Since vapor pressure of the soil surface and of the air became very similar at that time, soil E should be rather insignificant 10 days to 2 weeks after an irrigation.

The driving force for transpiration (ΔW) was calculated. Samples of the results in 1999 are given in Fig. 9 for two dates before an irrigation, the day of irrigation and the three days after the irrigation. It is seen in Fig. 9 that before the irrigation, ΔW was similar for much of the time each day between the WET and DRY plots, with ΔW for the DRY plots often slightly lower than that for the WET early in the afternoon. After the soil surface was wetted by the irrigation at 11:00 on July 23, ΔW became markedly smaller for the WET plot from in the morning. Six days after the irrigation, the difference in ΔW between the two treatments became much less.

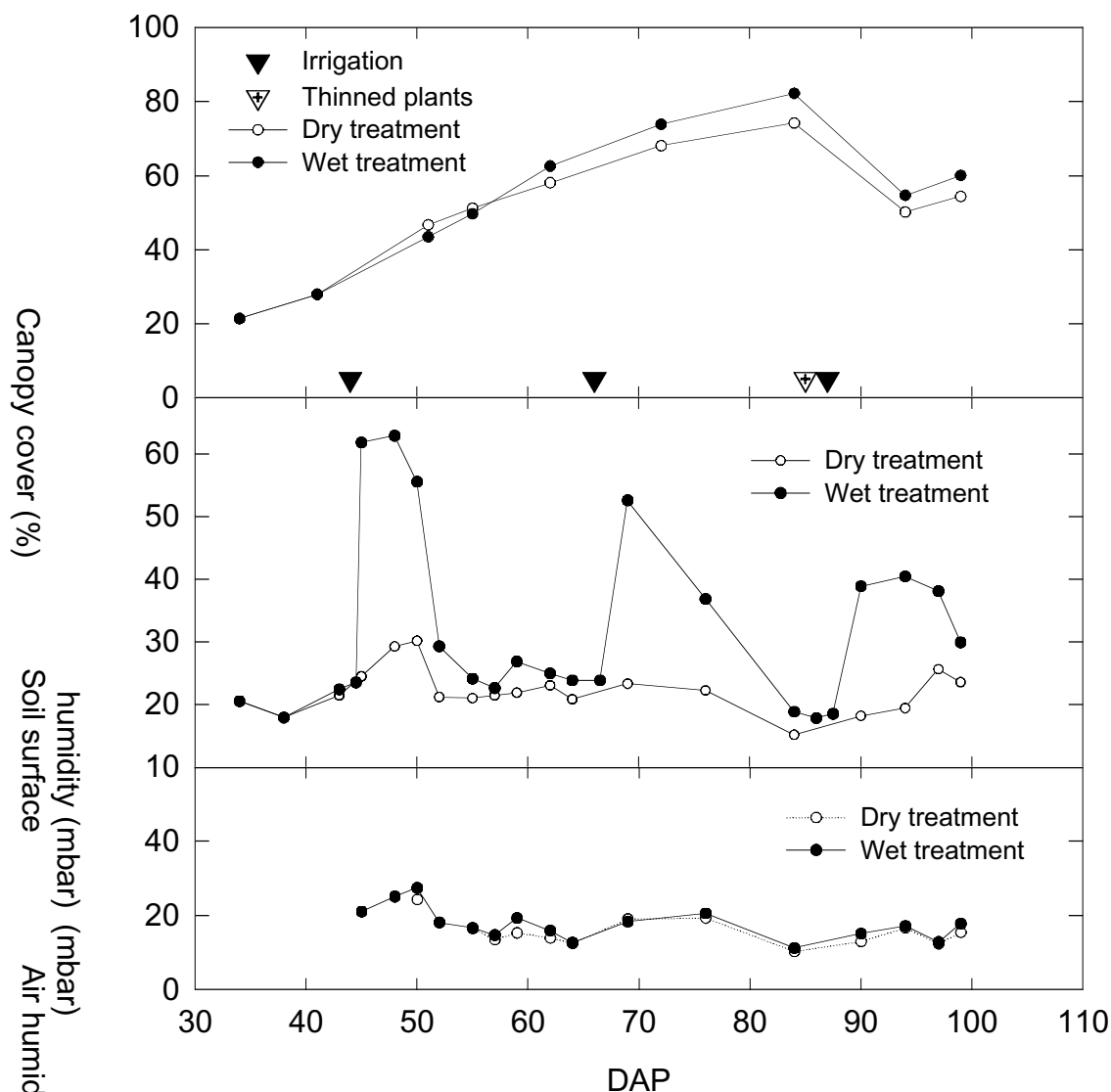


Figure 8. Absolute humidity (vapor pressure) of the exposed soil surface and of the air for the Wet treatment as affected by furrow irrigation (inverted solid triangles), and for the Dry treatment not receiving irrigation. Canopy cover of each treatment are also shown. On 85 DAP, the plant was thinned to about 2.5 plants m^{-2} to reduce the canopy cover in order to have a higher proportion of exposed soil surface.

The 2000 data of ΔW are presented as midday mean over a test period of over 70 days in Fig. 10. In the lower part of the figure the ratio of ΔW of the Dry treatment to ΔW of the wet treatment is shown. It is seen that this ratio increased substantially after each furrow irrigation, then declined over a period of several days to one week to a base value of 1.0.

Throughout the experiments in 1999 and 2000, there was no significant water stress in the plants of the DRY plot, as indicated by the absence of stress symptoms and a canopy size nearly the same as the WET

plot. That is due to the high water holding capacity of the deep Yolo loam soil at the experiment site, and fast development of the root system of many crops including cotton on this soil.

Using the estimated ΔW , the increase in canopy transpiration (T) caused by dry soil surface was calculated for the midday period over two irrigation cycles in 1999, and the results are presented in Fig. 11. Both treatments were irrigated the same way on 35 DAP and canopy T was similar for the WET and the DRY plots and the canopy cover was also similar. As expected, irrigation of the WET plot on 49 DAP caused a large difference in canopy T between the WET and DRY plots. This difference lessened gradually over time and became insignificant after about a week. The canopy grew from approximately 30 percent coverage of the soil at 49 DAP to 60 percent coverage of the soil on 63 DAP. The next irrigation of the WET plot, applied on 63 DAP, had no significant effect on canopy T. Most likely that was due to the fact that by then the canopy covered more than 60 percent of the soil, and heating of the small portion of the dry soil surface was insufficient to have a measurable effect on canopy temperature. Therefore the estimated canopy T was essentially not affected. Overall, compared to the intermittently wetted soil surface, dry soil surface was estimated to increase canopy transpiration by 17 percent over the 15 days of testing period (49 to 63 DAP).

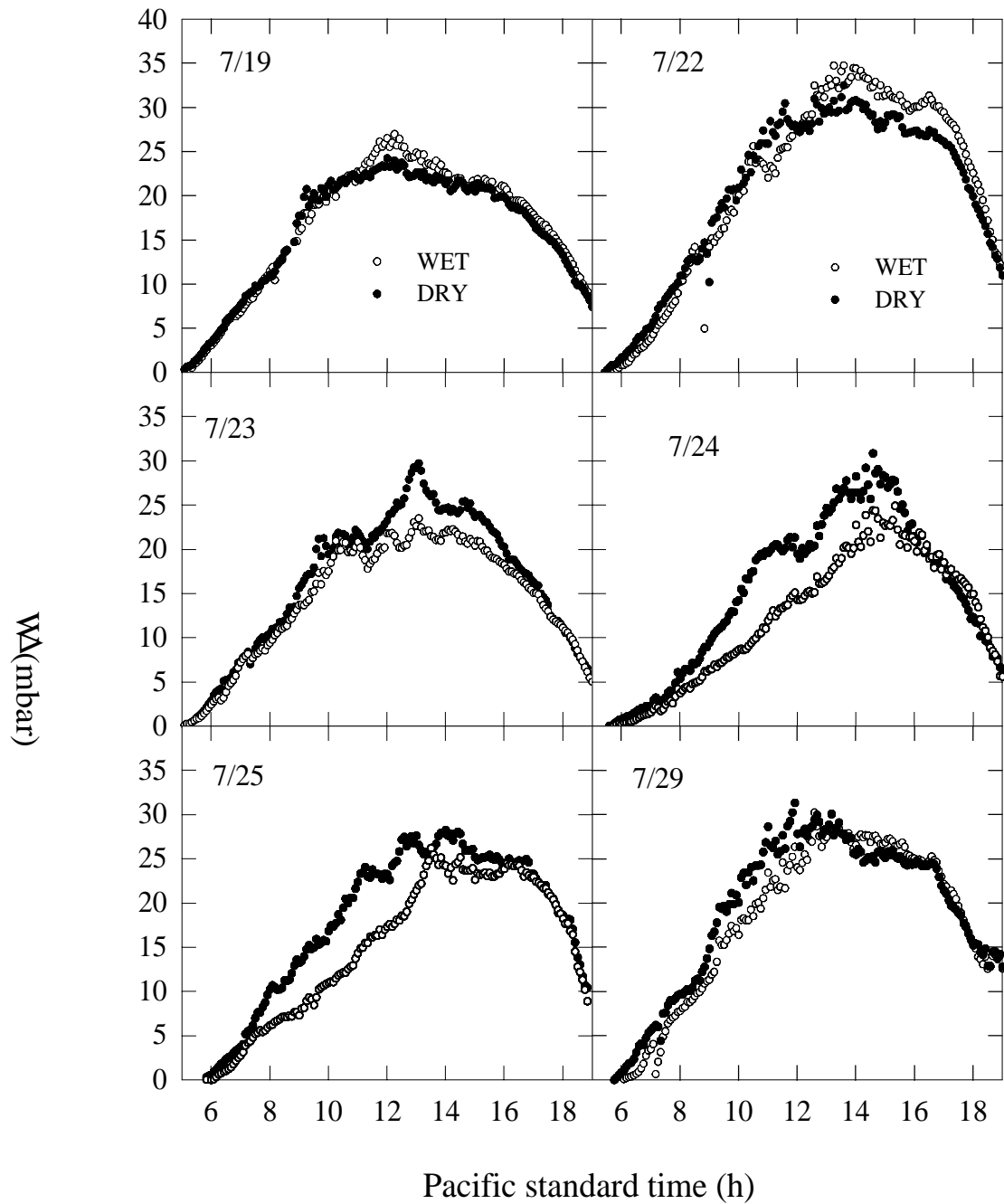


Figure 9. Vapor pressure difference (ΔW) between the interior of leaves and the air for cotton in the WET and DRY treatments on six dates in 1999. Irrigation of the WET plot was on 7/23 starting about 11:00.

It should be pointed out that the above estimates of the potential increase in canopy T are likely to be on the high side. The estimate was based on midday data, when intrarow advective effect is expected to be the greatest. Basing the estimate on the cumulative daily data would have reduced the estimate enhancement in canopy T. Also, in estimating canopy T the DRY plants were assumed to have the same canopy conductance as the WET plants. In reality, conductance was probably lower for the DRY than the WET plants because cotton stomata close more as ΔW increases (Xu, 2000), and therefore canopy T would not have been enhanced as much.

The results in both 1999 and 2000 indicate that eliminating or markedly reducing soil E would enhance canopy T significantly only when canopy coverage of the ground is small, and the effect is only substantial in the first several days after an irrigation. Thus, unless the soil surface is wetted by irrigation very frequently when canopy cover is small, the increase in canopy T for the season by eliminating the wetting of soil surface is likely to be minor.

General Discussion and Conclusion

This chapter is based both on a study of the literature and on substantial experimental work conducted at the University of California, Davis, over two years. The review of literature confirms what is generally, if vaguely, taken for granted. That is: when crop canopy cover of the soil is partial, canopy T is less than the rate of ET_o , and soil E is substantial when the soil surface is wet and exposed, and decreases as canopy cover increases. Although the number of reasonably definitive studies is limited, the results are fairly consistent and shows (Fig. 3) that when canopy cover of the soil is partial and soil surface wet, canopy T as a fraction of ET is not just proportional to the fractional canopy cover but greater; and soil E as a fraction of ET is not proportional to the fractional exposed soil surface but less. In other words, canopy appears to exert a disproportionately large impact on canopy T and on soil E. On the other hand, when canopy coverage of the soil is complete or very nearly so, there is still some soil E, in the order of 10 percent or less of ET.

Once the exposed soil surface begins to dry, soil E declines exponentially with time and the empirical data indicate that canopy T increases at least slightly as the result. This point is emphasized in the analysis by Ritchie (1983), of canopy T as a fraction of ET in relation to LAI. Nonetheless, the conclusion is not as firm as one would like because it is based on comparing T/ET data measured or estimated with different methods from different studies.

The experimental work conducted at Davis demonstrates clearly the influence of plant density on the speed of canopy development and hence on the extent of soil E relative to canopy T. Higher plant density and more canopy cover reduce soil E but increase canopy T. Consequently the total ET is usually increased but the amount of soil E is reduced, as demonstrated in Fig. 3 and 5. The increase in total ET caused by increased canopy T is beneficial, in that more biomass is produced by the crop per unit of ET. That is, the efficiency of consumptive water use for biomass production is improved.

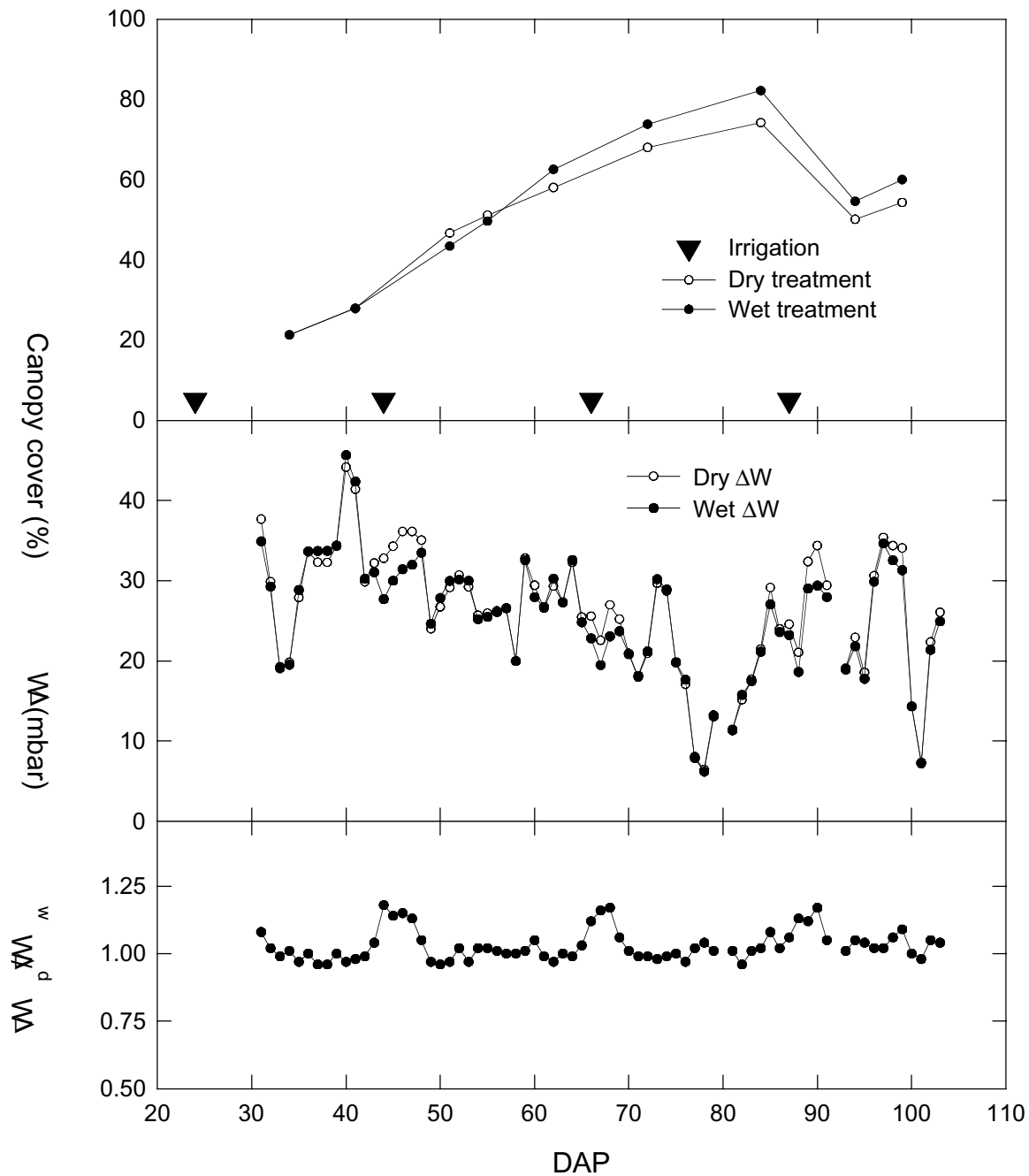


Figure 10. Difference in midday (11:30 to 12:30 PST) water vapor pressure (ΔW) between the foliage interior and the bulk air for the Dry and Wet cotton in 2000, and the ratio of ΔW for the Dry treatment to ΔW for the Wet treatment. Irrigation (inverted arrow heads) on 24 DAP was applied to both treatments, but subsequently only to the Wet treatment. On 85 DAP, the stand was thinned to 2.5 plants m^{-2} . ΔW was calculated from foliage temperature and bulk air vapor pressure.

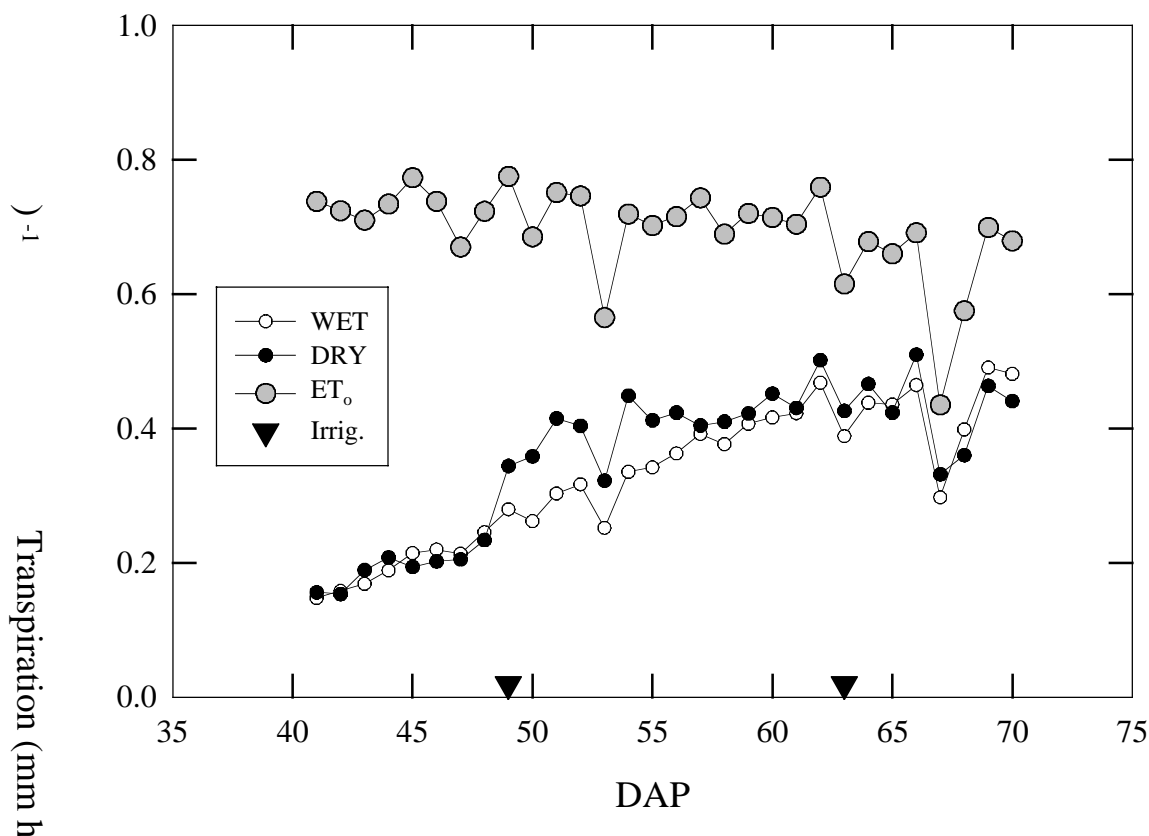


Figure 11. Calculated effect of soil drying on canopy transpiration for the midday period of 11:30 to 12:30. Solid and open symbols are for DRY and WET treatments, respectively. Inverted triangles indicate the time of irrigation of the WET treatment. Transpiration was calculated using ΔW data as indicated in the text.

Another aspect of the experimental work compared ET of cotton irrigated by drip with that irrigated by furrow. Without irrigation ET spikes, the pattern of daily ET over time for the drip irrigated is very different from that for the furrow irrigated (Fig. 6a). For cumulative ET over the experimental period, the data are not totally conclusive because the lysimeter of the drip irrigated treatment developed a salinity problem that slowed the growth of cotton before it was corrected. Minor adjustment of the ET data were made to account for this difference in canopy cover. Cumulative ET calculated from the adjusted data (Fig. 6c) indicates that consumptive water use of the drip irrigated treatment was essentially the same as that of the furrow irrigated treatment (436 mm vs. 426 mm). These results support the conclusions drawn in several other studies (e.g., Tarantino et al., 1982) that drip irrigation may not reduce soil E under some conditions. Drip irrigation is likely to reduce ET through the reduction in soil E in comparison to surface irrigation if one or more of the following conditions apply: (a) the time interval between drip irrigations is longer than that used in this study; (b) the time interval between furrow irrigations is shorter than that used in this study; and (c) the canopy cover develops more slowly (e.g., by planting at a lower density or by being deficient in mineral nutrients, or growing a species of crop with a slower growth rate) than that observed in this study. It is obvious that a number of other factors such as soil water holding capacity,

rooting depth, and sensitivity of the crop to low soil water status enter into consideration when deciding on irrigation intervals in addition to the potential reduction in soil E.

The extent that ET from the soil and from the crop is suppressed during sprinkler water application was also carefully assessed in many tests over the two year period in Davis. ET rate had to be calculated as the difference between the water application rate as measured by catch cans and the rate of water gain by the field as measured by precision lysimeters. Due to the fact that ET rate is small when compared to the rate of water application by impulse sprinklers, the results are quite variable. By conducting a total of nine successful tests, it is possible to conclude that ET is suppressed during the time of sprinkler irrigation, by probably 40 to 50 percent in comparison to ET from a wet field without the sprinkling. The suppression is the result of the spraying water drops from the sprinklers humidifying and cooling the air. Thus, the in-air evaporation from the falling water drops is not all vain, in that some saving of ET results. The saving is not greater because rotation of the sprinkler heads places the spray over a particular area only periodically. The general impression is that sprinkler irrigation involves extra water loss due to in-air evaporation of the drops. The extent of this evaporation has been calculated in a theoretical way, based on drop size distribution, traveling distance, and wet bulb depression as a function of air humidity. This effort should be expanded and combined with experimental measurements to better assess the in-air evaporation of sprinkler systems. The in-air evaporation rate can then be compared with the extent of ET suppression to ascertain just how much extra water is lost during sprinkler irrigations.

The final part of the experimental work was to estimate the potential increase of canopy transpiration if soil evaporation is greatly reduced or eliminated. This was done by measuring increases in foliage temperature when soil surface was dry compared to when it was wet, under conditions when canopy covered the soil only partly. Using the fact that leaf interior is essentially saturated with water vapor and the well known saturation vapor pressure vs. temperature curve, the potential effect on transpiration was estimated from the increases in water vapor gradient from the foliage to the bulk air driving transpiration. The results show that in the worst case scenario, canopy T over a dry soil surface may be 30 percent higher than over a fully wet soil surface, and the difference narrows and became insignificant as the soil surface dries over time. The common time interval between surface irrigations is in terms of a week to many days, ample time for the drying of exposed soil surface. Hence, when averaged over a period of weeks or more the difference in canopy T over a dry soil compared to a soil wetted periodically by irrigation should be considerably less. In the case we evaluated, the average difference was 17 percent for a period when the canopy cover was low. Generally speaking then, there would be some increase in canopy T when canopy cover is incomplete if soil E is essentially eliminated by irrigating with buried drip systems. The elimination of soil E, however should still result in a significant saving in total ET or consumptive water use.

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SIMETAW

(Simulation of Evapotranspiration of Applied Water)

The SIMETAW program was developed to simulate weather data from monthly climate data and to estimate reference evapotranspiration (ET_o) and crop evapotranspiration (ET_c) with the simulated data. In addition, simulated daily rainfall, soil water holding characteristics, effective rooting depths, and ET_c are used to determine effective rainfall and to generate hypothetical irrigation schedules to estimate the seasonal and annual evapotranspiration of applied water (ET_{aw}), where ET_{aw} is an estimate of the crop evapotranspiration minus any water supplied by effective rainfall. The simulation program allows one to investigate how climate change might affect the water demand in California. All of the ET_{aw} calculations are done on a daily basis, so the estimation of effective rainfall and, hence, ET_{aw} is greatly improved over earlier methods. In addition, the use of the widely adopted Penman-Monteith equation for reference evapotranspiration (ET_o) and improved methodology to apply crop coefficients for estimating crop evapotranspiration is used to improve ET_{aw} accuracy.

Methodology

Weather Simulation

Weather simulation models are often used in conjunction with other models to evaluate possible crop responses to environmental conditions. One important response is crop evapotranspiration (ET_c). Crop evapotranspiration is commonly estimated by multiplying reference evapotranspiration by a crop coefficient. In SIMETAW, daily data are used to estimate reference evapotranspiration. Rainfall data are then used with estimates of ET_c to determine ET_{aw} . One can either use raw or simulated daily data for the calculations.

Rainfall

Characteristics and patterns of rainfall are highly seasonal and localized, so making a general, seasonal model that is applicable to all locations is difficult. Recognizing the fact that rainfall patterns are usually skewed to the right toward extreme heavy amount and that the rain status of previous day tends to affect present day's condition, a gamma distribution and Markov chain modeling approach was applied to describe rainfall patterns for periods within which rainfall patterns are relatively uniform [1–4]. This approach consists of two models: two-state, first order Markov chain and a gamma distribution function. These models require long-term daily rainfall data to estimate model parameters. SIMETAW however, uses monthly averages of total rainfall amount and number of rain days to obtain all parameters for the Gamma and Markov Chain models.

Wind Speed

The simulation of wind speed is a simpler procedure, requiring only the gamma distribution function, as described for rainfall. While using a gamma distribution provides good estimates of extreme values of wind speed, there is a tendency to have some unrealistically high wind speed values generated for use in ET_o calculations. Because wind speed depends on atmospheric pressure gradients, no correlation between wind speed and the other weather parameters used to estimate ET_o exists. Therefore, the random matching of high wind speeds with conditions favorable to high evaporation rates leads to unrealistically high ET_o estimates on some days. To eliminate this problem, an upper limit for simulated wind speed was set at

twice the mean wind speed. This is believed to be a reasonable upper limit for a weather generator used to estimate ET_o because extreme wind speed values are generally associated with severe storms and ET_o is generally not important during such conditions.

Temperature, Solar Radiation, and Humidity

Temperature, solar radiation, and humidity data usually follow a Fourier series distribution. Therefore, the model of these variables may be expressed as:

$$X_{ki} = \mu_{ki} (1 + \delta_{ki} C_{ki}) \quad (1)$$

where $k = 1, 2$ and 3 ($k=1$ represents maximum temperature; $k = 2$ represents minimum temperature; and $k=3$ represents solar radiation). μ_{ki} is the estimated daily mean and C_{ki} is the estimated daily coefficient of variation of the i^{th} day, $i = 1, 2, \dots, 365$ and for the k^{th} variable.

SIMETAW simplifies the parameter estimation procedure of Richardson and Wright [4], requiring only monthly means as inputs. From a study of 34 locations within the United States, the coefficient of variability (CV) values appear to be inversely related to the means. The same approach is used to calculate the daily CV values. In addition, a series of functional relationships between the parameters of the mean curves and the parameters of the coefficient of variation curves, which made it possible to calculate C_{ki} coefficients from μ_{ki} curves without additional input data requirement, were developed.

Simulation Accuracy

Nine years of daily measured weather data (1990 – 1998) from the California Irrigation Management Information System (CIMIS) in Davis were used in the model to simulate 30 years of daily weather data. The weather data consist of R_s , T_{max} , T_{min} , wind speed, T_{dew} , and Rainfall. The weather data simulated from SIMETAW were compared with the data from CIMIS. Results in Figures 1, 2, and 3 showed that R_s , T_{max} , and Rainfall values predicted from SIMETAW were well correlated with those values obtained from CIMIS. Similar results were also observed for T_{min} , wind speed, and T_{dew} data.

Figure 1
Comparison of measured and simulated daily solar radiation data at Davis, California

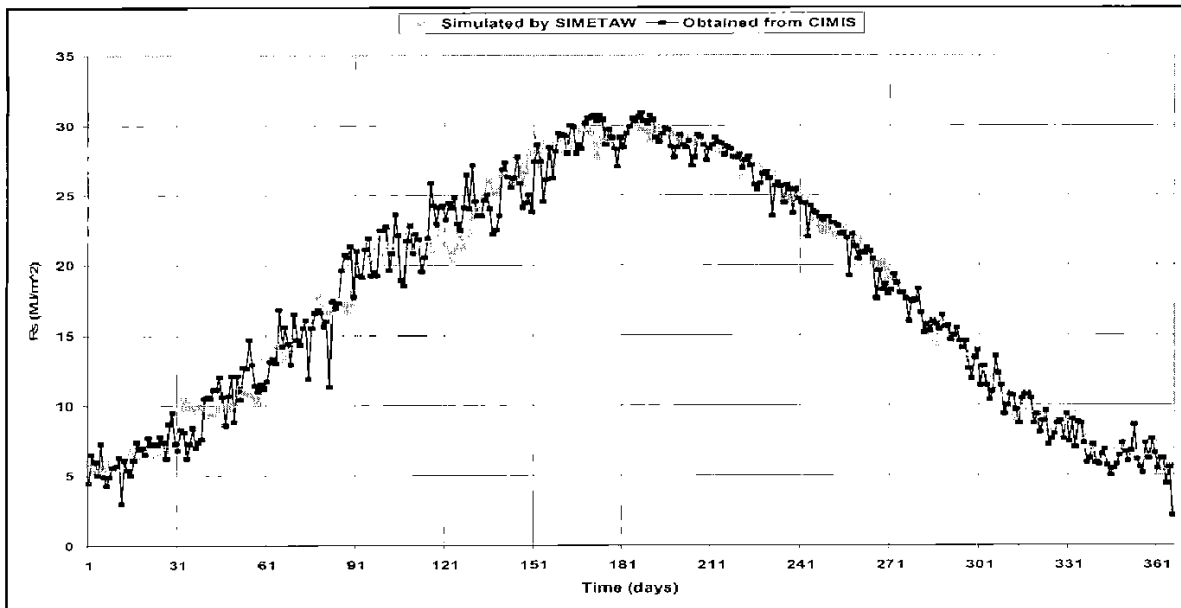


Figure 2
Comparison of measured and simulated daily maximum air temperature data at Davis, California

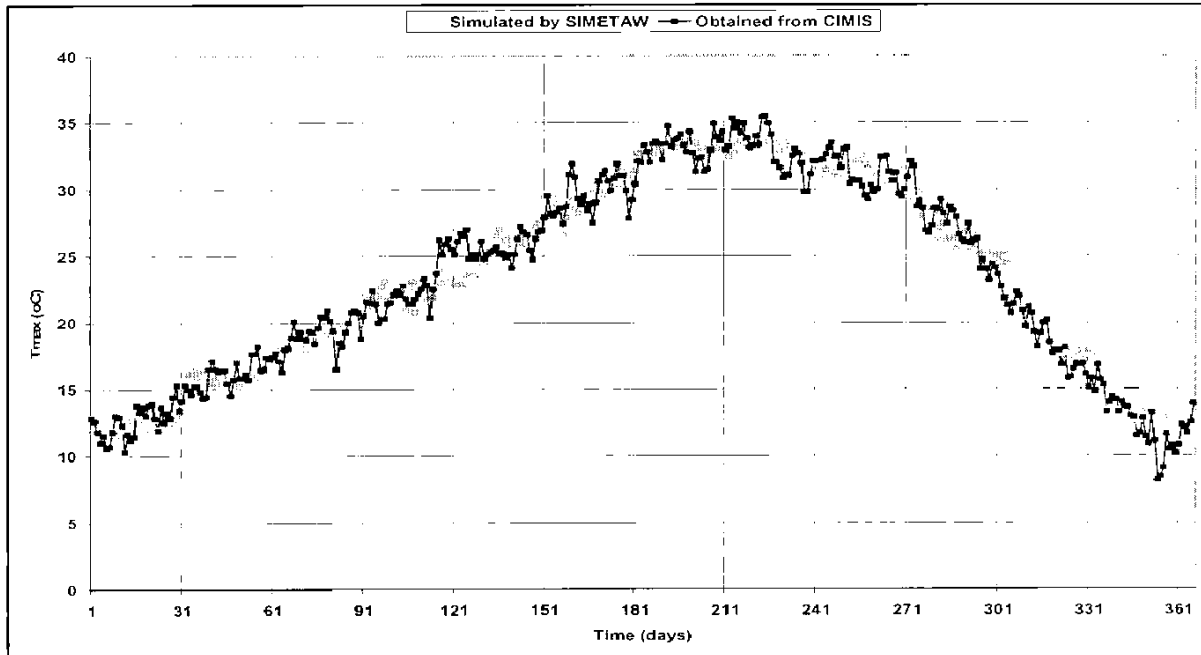
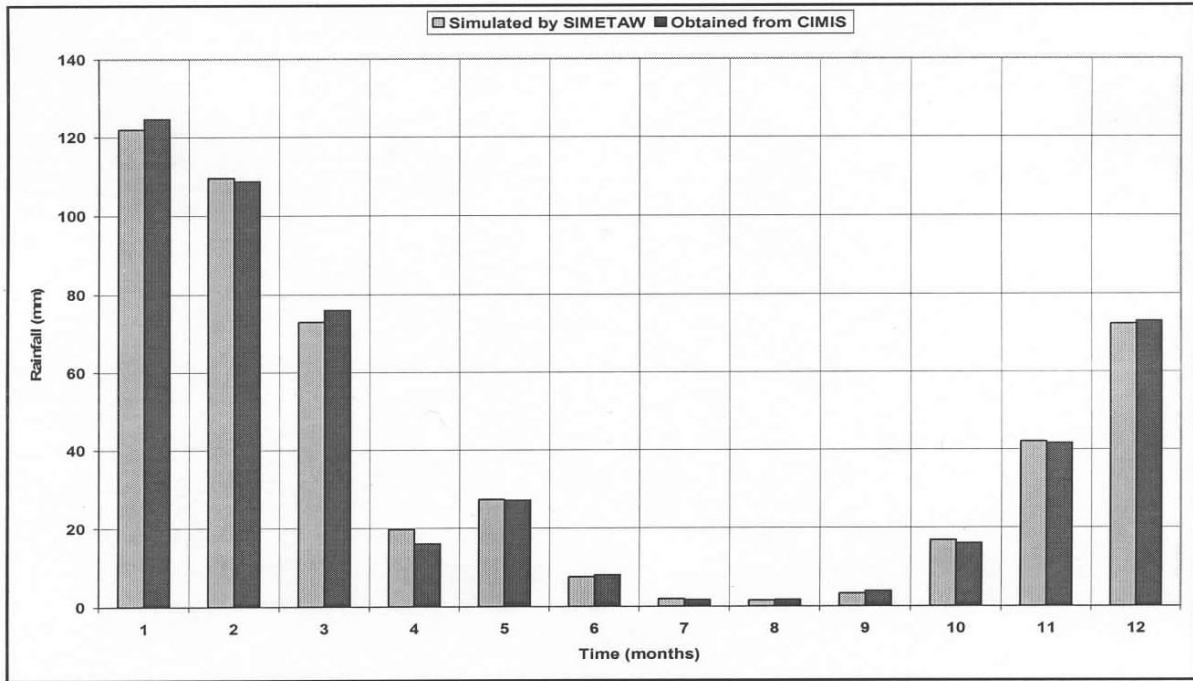


Figure 3
Comparison of measured and simulated monthly rainfall data at Davis, California



Reference Evapotranspiration Calculation

Reference evapotranspiration (ET_o) is estimated from daily weather data using a modified version of the Penman-Monteith equation [5–7]. The equation is:

$$ET_o = \frac{0.408 \Delta (R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34 u_2)} \quad (2)$$

where Δ is the slope of the saturation vapor pressure at mean air temperature curve ($\text{kPa } ^\circ\text{C}^{-1}$), R_n and G are the net radiation and soil heat flux density in $\text{MJ m}^{-2}\text{d}^{-1}$, γ is the psychrometric constant ($\text{kPa } ^\circ\text{C}^{-1}$), T is the daily mean temperature ($^\circ\text{C}$), u_2 is the mean wind speed in m s^{-1} , e_s is the saturation vapor pressure (kPa) calculated from the mean air temperature ($^\circ\text{C}$) for the day, and e_a is the actual vapor pressure (kPa) calculated from the mean dew point temperature ($^\circ\text{C}$) for the day. The coefficient 0.408 converts the $R_n - G$ term from $\text{MJ m}^{-2}\text{d}^{-1}$ to mm d^{-1} and the coefficient 900 combines together several constants and converts units of the aerodynamic component to mm d^{-1} . The product $0.34 u_2$, in the denominator, is an estimate of the ratio of the 0.12-m tall canopy surface resistance ($r_c=70 \text{ s m}^{-1}$) to the aerodynamic resistance ($r_a=205/u^2 \text{ s m}^{-1}$). It is assumed that the temperature, humidity and wind speed are measured between 1.5 m (5 ft) and 2.0 m (6.6 ft) above the grass-covered soil surface. For a complete explanation of the equation, see Allen and others [5]. If only temperature data are available, then the SIMETAW calculates daily ET_o using the Hargreaves-Samani equation. The equation may be written:

$$ET_o = 0.0023 (T_c + 17.8) R_a (T_d)^{1/2} \quad (3)$$

Where T_c is the monthly mean temperature (degrees centigrade), R_a is the extraterrestrial solar radiation expressed in mm/month, and T_d is the difference between the mean minimum and mean maximum temperatures for the month (degrees centigrade).

If pan data are used in the program, then the program automatically estimates daily ET_o rates using a fetch value (i.e. upwind distance of grass around the pan). The approach in the SIMETAW provides a simple method to estimate ET_o from E_{pan} data without the need for wind speed and relative humidity data.

Verification of the Simulated Reference Evapotranspiration

As a final verification of the SIMETAW model, we compared our model predictions of ET_o with number of years of estimated daily ET_o data from CIMIS (California Irrigation Management Information System) at Davis, Oceanside, and Bishop. The performance of our model ET_o predictions was evaluated at sites influenced by coastal and windy desert climates. Figures 4, 5, and 6 compare daily mean ET_o estimates of SIMETAW and CIMIS averaged over the period of records. As seen in figures, a close agreement between CIMIS-based estimates of ET_o and those of the SIMETAW model exists. Bishop is influenced by a windy desert environment on the eastern side of the Sierra Nevada range. Oceanside is a coastal site in San Diego County. Davis is in the Central Valley, which is characterized by clear, hot, dry days with strong, cooling southwest winds during afternoons in the summer.

Figure 4
Comparison of daily ET_o estimates from SIMETAW and CIMIS at Davis, California

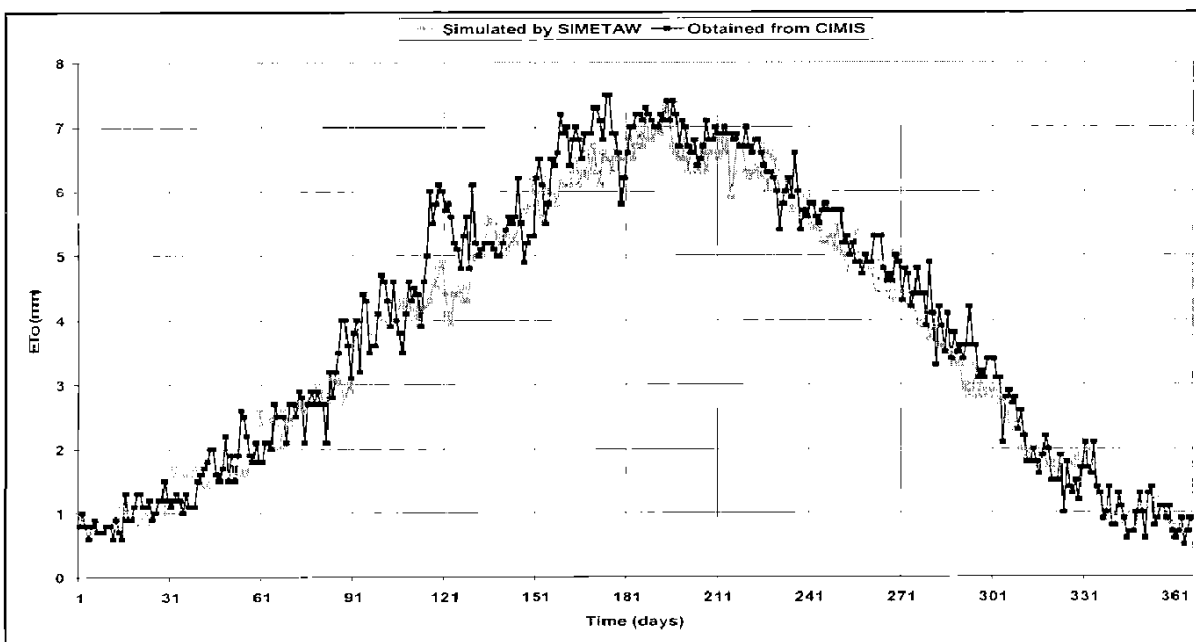


Figure 5
Comparison of daily ET_o estimates from SIMETAW and CIMIS at Oceanside, California

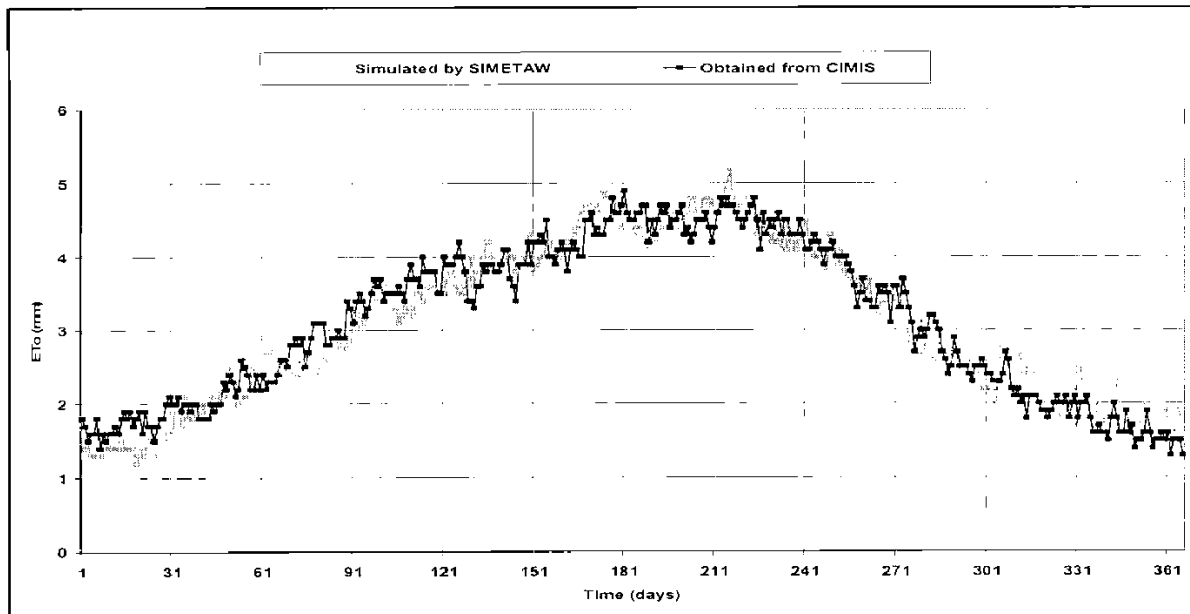
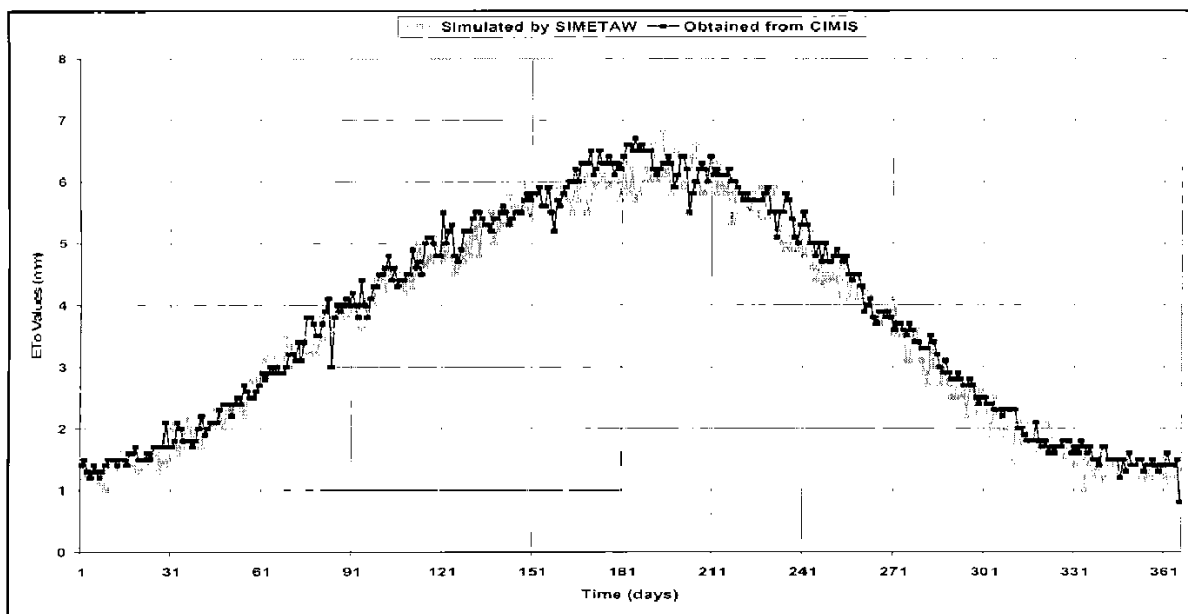


Figure 6
Comparison of daily ET_o estimates from SIMETAW and CIMIS at Bishop, California



Input Climate Data

Either daily or monthly climate data are used to determine ET_{aw} in SIMETAW. The daily data can come from CIMIS (California Irrigation Management Information System) or from a non-CIMIS data source as long as the data are in the correct format. After reading the data, ET_{aw} can be calculated directly from the raw daily data. In addition, the monthly means can be calculated from the daily files and then daily data

are generated using the simulation program. Since daily data were input directly, the calculation of monthly data for use in simulation of daily data is unnecessary. However, it was included to test if similar results are obtained using raw or simulated data.

The monthly data can be read from a file or calculated from daily CIMIS or non-CIMIS data files, or from some other source. The monthly data file must have the proper, comma-delimited format. SIMETAW will generate daily weather data for a specified period of record from the monthly data.

SIMETAW either generates a daily data file from monthly data or uses a raw data file consisting of daily solar radiation, maximum, minimum and dew point temperature, and wind speed for calculating daily ET_o . After calculating ET_o , if the data were generated, the program sorts the rainfall data within each month to force a negative correlation between rainfall amount and ET_o rate. Only the rainfall dates are sorted and there is no change in the dates for the weather and ET_o data. Further more, the program can simulate daily ET_o data directly from monthly means of ET_o and E_{pan} data.

Crop Coefficients

While reference crop evapotranspiration accounts for variations in weather and offers a measure of the ‘evaporative demand’ of the atmosphere, crop coefficients account for the difference between the crop evapotranspiration and ET_o . The main factors affecting the difference are (1) light absorption by the canopy, (2) canopy roughness, which affects turbulence, (3) crop physiology, (4) leaf age, and (5) surface wetness. Because evapotranspiration (ET) is the sum of evaporation (E) from soil and plant surfaces and transpiration (T), which is vaporization that occurs inside of the plant leaves, it is often best to consider the two components separately. When not limited by water availability, both transpiration and evaporation are limited by the availability of energy to vaporize water. During early growth of crops, when considerable soil is exposed to solar radiation, ET_c is dominated by soil evaporation and the rate depends on whether or not the soil surface is wet. If a nearly bare-soil surface is wet, the ET_c rate is slightly higher than ET_o , when evaporative demand is low, but it will fall to about 80 percent of ET_o under high evaporation conditions. However, as a soil surface dries off, the evaporation rate decreases considerably. As a canopy develops, solar radiation (or light) interception by the foliage increases and transpiration rather than soil evaporation dominates ET_c . Assuming there is no transpiration-reducing water stress, light interception by the crop canopy is the main factor determining the ET_c rate. Therefore, crop coefficients for field and row crops generally increase until the canopy ground cover reaches about 75 percent. For tree and vine crops the peak K_c is reached when the canopy has reached about 70 percent ground cover. The difference between the crop types results because the light interception is somewhat higher for the taller crops.

Crop Coefficient Estimation

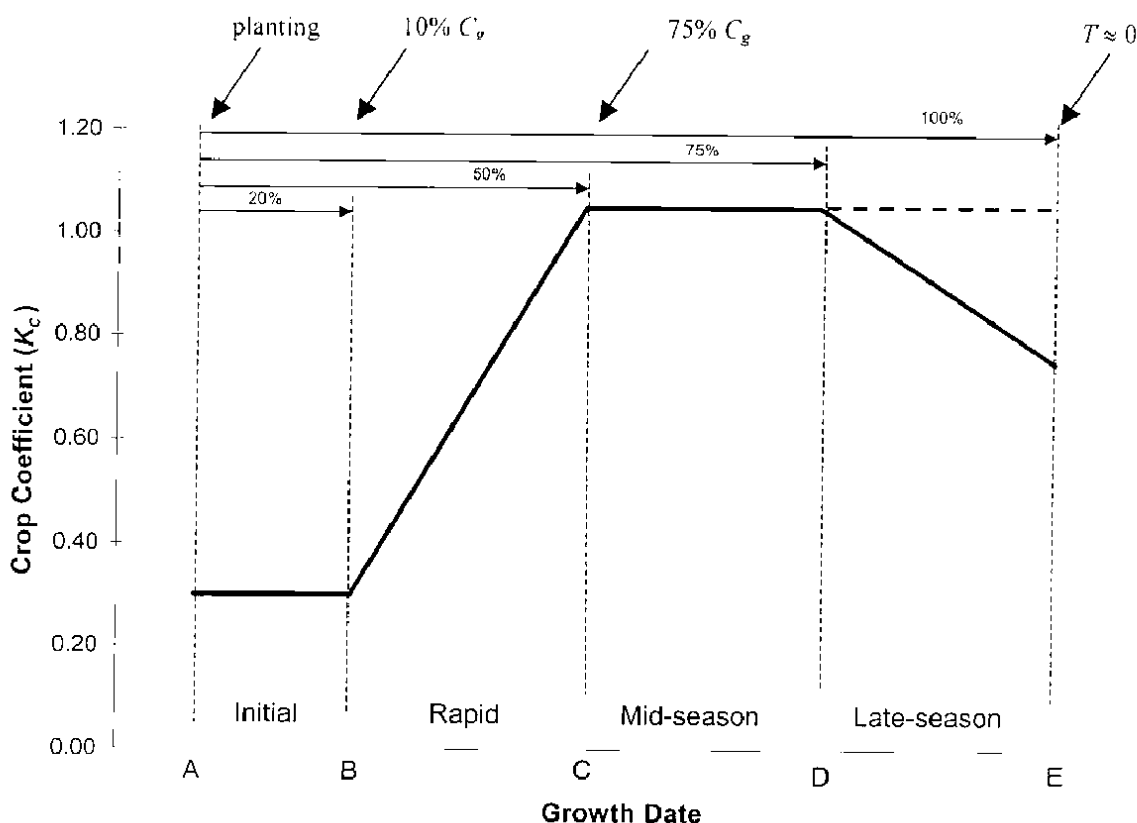
Crop coefficients are calculated using a modified Doorenbos and Pruitt [10] method. The season is separated into initial (date A-B), rapid (date B-C), midseason (date C-D), and late season (date D-E) growth periods.

Field and Row Crops

Tabular default K_c values corresponding to important inflection points in Figure 7 are stored in the SIMETAW program. The value K_{c1} corresponds to the date B K_c (K_{cB}). For field and row crops, K_{c1} is used from date A to B. The value K_{c2} is assigned as the K_c value on date C (K_{cC}) and D (K_{cD}). Initially,

the K_cC and K_cD values are set equal to K_c2 , but for tree and vine crops, the values for K_cC and K_cD are adjustable for the percentage shading by the canopy to account for sparse or immature canopies. During the rapid growth period, when the field and row crop canopy increases from about 10 percent to 75 percent ground cover, the K_c value changes linearly from K_cB to K_cC . For deciduous tree and vine crops, the K_c increases from K_cB to K_cC as the canopy develops from leaf out on date B to about 70 percent shading on date C. During late season, the K_c changes linearly from K_cD on date D to K_cE at the end of the season. The values for K_cB and K_cC depend on the difference in (1) energy balance due to canopy density and reflective qualities, (2) crop morphology effects on turbulence, and (3) physiological differences between the crop and reference crop.

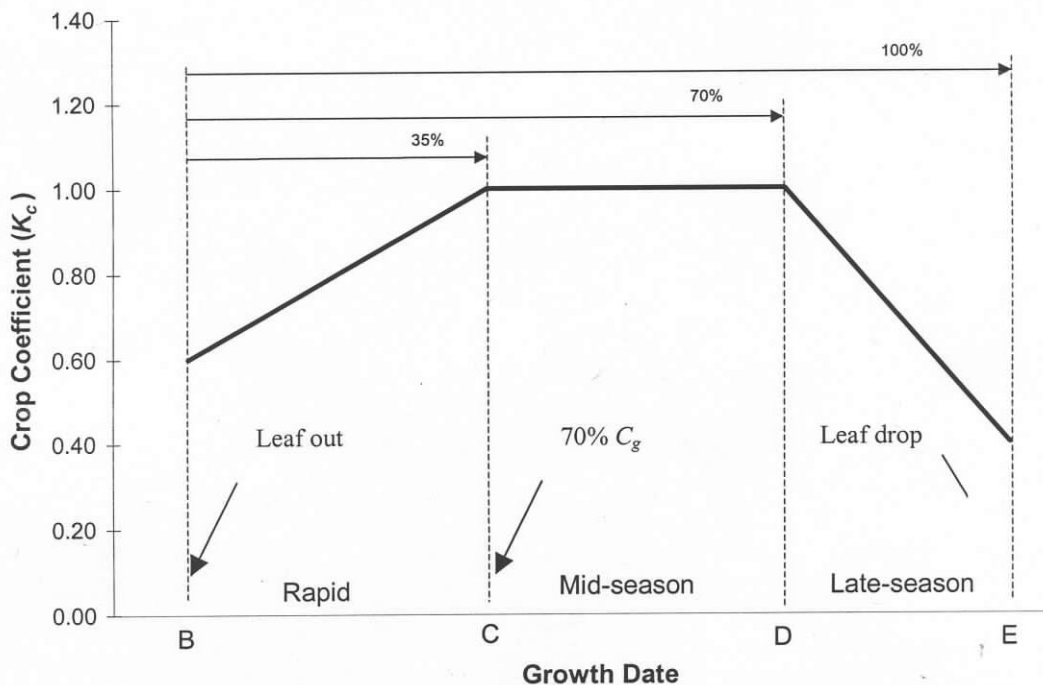
Figure 7
Hypothetical Crop Coefficient (K_c) Curve for Typical Field and Row Crops Showing Growth Stages and Percentages of the Season from Planting to Critical Growth Dates



Deciduous Tree and Vine Crops

Deciduous tree and vine crops, without a cover crop, have similar K_c curves but without the initial growth period (Fig. 8). The season begins with rapid growth at leafout when the K_c increases from K_cB to K_cC . The midseason period begins at approximately 70 percent ground cover. Then, unless the crop is immature, the K_c is fixed at K_cC until the onset of senescence on date D ($K_c2=K_cC=K_cD$). During late season, when the crop plants are senescing, the K_c decreases from K_cD to K_cE . The end of the season occurs at about leaf drop or when the tree or vine transpiration is near zero.

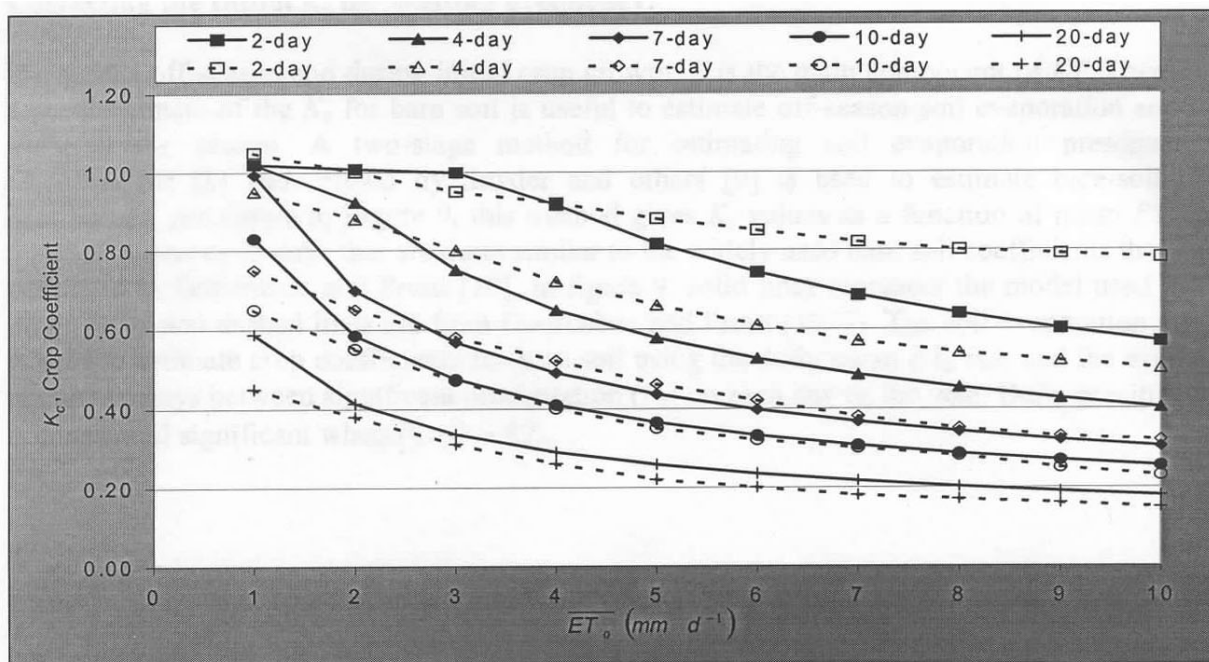
Figure 8
Hypothetical Crop Coefficient (K_c) Curve for Typical Deciduous Orchard and Vine Crops Showing Growth Stages and Percentages of the Season from Leaf Out to Critical Growth Dates



Correcting the Initial K_c for Wetting Frequency

During the off-season and during initial crop growth, E is the main component of ET . Therefore, a good estimate of the K_c for bare soil is useful to estimate off-season soil evaporation and ET_c early in the season. A two-stage method for estimating soil evaporation presented by Stroonsnjider [8] and refined by Snyder and others [9] is used to estimate bare-soil crop coefficients. As shown in Figure 9, this method gives K_c values as a function of mean ET_o and wetting frequency in days that are quite similar to the widely used bare soil coefficients that were published in Doorenbos and Pruitt [10]. In figure 9, solid lines represent the model used in the SIMETAW and dashed lines are from Doorenbos and Pruitt (1977). The soil evaporation model is used to estimate crop coefficients for bare soil using the daily mean ET_o rate and the expected number of days between significant precipitation (P_s) on each day of the year. Daily precipitation is considered significant when $P_s > 2 \times ET_o$.

Figure 9
Crop Coefficient (K_c) Values for Nearly Bare-Soil Evaporation as
Function of Mean ET_o Rate and Wetting Frequency in Days



Correcting the K_c for Immature Trees and Vines

This program accounts for immaturity effects on crop coefficients for tree and vine crops. Immature deciduous tree and vine crops use less water than mature crops. The following equation is used to adjust the mature K_c values (K_{cm}) as a function of percentage ground cover (C_g).

$$\text{If } \sin\left(\frac{C_g \pi}{70 \cdot 2}\right) \geq 1.0 \text{ then } K_c = K_{cm} \text{ else } K_c = K_{cm} \left[\sin\left(\frac{C_g \pi}{70 \cdot 2}\right) \right] \quad (4)$$

Correcting the K_c for Immature Subtropical Orchards

For an immature orchard, the mature K_c values (K_{cm}) are adjusted for their percentage ground cover (C_g) using the following criteria.

$$\text{If } \sqrt{\sin\left(\frac{C_g \pi}{70 \cdot 2}\right)} \geq 1.0 \text{ then } K_c = K_{cm} \text{ or else } K_c = K_{cm} \sqrt{\sin\left(\frac{C_g \pi}{70 \cdot 2}\right)} \quad \vee \quad (5)$$

Correcting for Cover Crops

With a cover crop, the K_c values for deciduous trees and vines are higher. When a cover crop is present, 0.35 is added to the clean-cultivated K_c . However, the K_c value is not allowed to exceed 1.15 or to fall

below 0.90. SIMETAW allows beginning and end dates to be entered for two periods when a cover crop is present in an orchard or vineyard.

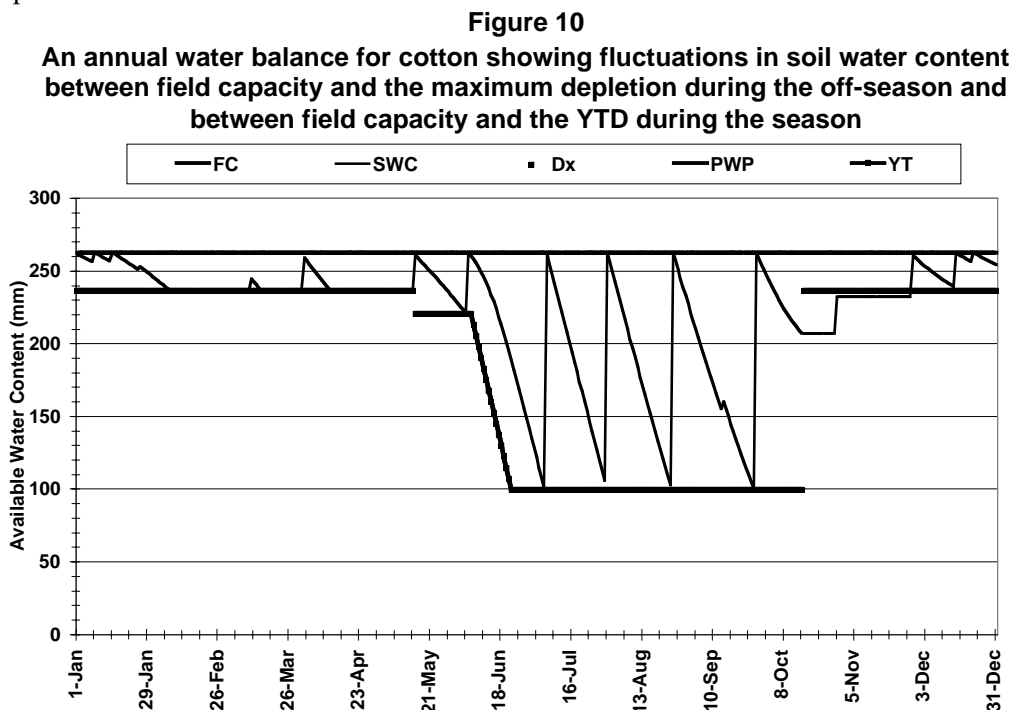
Field Crops with Fixed Crop Coefficients

Fixed annual K_c values are possible for some crops with little loss in accuracy. These crops include pasture, warm-season and cool-season turfgrass, and alfalfa averaged over a season. In the SIMETAW program, these field crops are identified as type-2 crops.

ET of Applied Water Calculations

The ET_o data come from the 'name.wrk' file, which is created from either input raw or simulated daily weather data. The K_c values are based on the ET_o data and crop, soil, and management specific parameters from a row in the 'DAUnnn.csv' file. During the off-season, crop coefficient values are estimated from bare soil evaporation as previously described. It is assumed that all water additions to the soil come from rainfall and losses are only due to deep percolation. Rainfall runoff as well as surface water running onto a cropped field is ignored. Because the water balance is calculated each day, this assumption is reasonable.

During the off-season, if the soil water depletion (SWD) is less than the YTD, ET_c is added to the previous day's SWD to estimate the depletion on the current day. However, the maximum depletion allowed is 50 percent of the PAW in the upper 30 cm of soil. If the SWD at the end of a growing season starts at some value greater than the maximum soil water depletion, then the SWD is allowed to decrease with rainfall additions but it is not allowed to increase with ET_c (Fig. 10). If half of the available water is gone from the upper 30 cm, it is assumed that the soil surface is too dry for evaporation. Once the off-season SWD is less than the maximum depletion, it is again not allowed to exceed the maximum off-season depletion.



If a crop is pre-irrigated, then the SWD is set equal to zero on the day preceding the season. If it is not pre-irrigated, then the SWD on the day preceding the season is determined by water balance during the off-season before planting or leafout. It is assumed that the SWD equals zero on December 31 proceeding the first year of data. After that the SWD is calculated using water balance for the entire period of record. During the growing season, the SWD depletion is updated by adding the ET_c (or by subtracting ET_c from the soil water content 'SWC') on each day (Fig. 3). If rainfall occurs, SWD is reduced by an amount equal to the rainfall. However, the SWD is not allowed to be less than zero. This automatically determines the effective rainfall as equal to the recorded rainfall if the amount is less than the SWD. If the recorded rainfall is more than the SWD, then the effective rainfall equals the SWD. Irrigation events are given on dates when the SWD would exceed the YTD. It is assumed that the SWD returns to zero on each irrigation date. The ETAW is calculated both on a seasonal and an annual basis as the cumulative ET_c minus the effective rainfall. The calculations are made for each year over the period of record as well as an overall average over years. The results are output to a summary table.

General Applications

Although the Simulation of Evapotranspiration of Applied Water (SIMETAW) program was written specifically to estimate ET_{aw} for estimating irrigation water requirements for use in water demand planning, the program is quite powerful and it has many additional applications. For hydrology, the SIMETAW application program can provide the evapotranspiration boundary conditions for ground and surface water models, which can lessen the potential for floods and can improve the management of water banking, aquifers, dams and reservoirs, and sea water intrusion in the Sacramento-San Joaquin Delta. In addition, the program can be used to help California growers to obtain improved crop coefficients for use in irrigation management. Use of SIMETAW to determine water demand by region can help with the management of water transfers throughout the State. Because the program generates many years of simulated weather data from monthly climate data, it can be used to study how changes in the monthly means might affect weather in the future. This can have implications as far as frost protection, which causes more economic losses in the United States than any other weather related phenomenon. Climatic changes in temperature, rainfall patterns, and humidity could all influence future daily weather conditions and could lessen or increase the probability of freezing temperatures. Changes in climate and the effect on daily weather can also influence air pollution within the State and SIMETAW can be used to simulate possible scenarios.

Air pollution is clearly a major problem in California and SIMETAW could help to identify an increased potential for major pollution events that could result from changes in rainfall patterns, temperature, etc. Another major problem in California is wildfire, which could worsen if the climate changes. SIMETAW can be used to study the impact of changes in monthly climate data on future weather conditions. This could impact biomass production in forests and rangeland, and changes in weather conditions could influence whether or not the natural ecosystems will experience more water stress and make them more prone to fire events. Of course, changes in the climate could impact on human health because of effects on air pollution as well as extremes of temperature. SIMETAW can provide scenarios of possible weather extremes resulting from changes in monthly climate data. SIMETAW can also be applied to refine the monthly mean ET_o rates (in/day) of California ETo Zone map. In addition, SIMETAW can be used as a tool to fill in missing data points from long-term data sets, which could be helpful for developing rainfall-runoff models, etc. Currently, there is considerable research on the use of regulated deficit irrigation (RDI) to more efficiently use water in crop production, which could potentially decrease water demand.

The SIMETAW program has a stress factor built in to account for reductions in ET_{aw} due to the use of RDI.

More information on SIMETAW is available at DWR's Web site:
www.waterplan.water.ca.gov/landwateruse/wateruse/Ag/wuagricultural.htm

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Global Climate Change

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Climate Change and California Water Resources: A Survey and Summary of the Literature

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Disclaimer

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Another product of this effort is a new, searchable, electronic bibliography of the water and climate literature. Over 3,000 citations are available to be searched by title, author, keyword, region, and more, at www.pacinst.org/resources.

The Public Interest Energy Research Program (PIER) of the California Energy Commission is an integrated, multidisciplinary effort to explore the potential implications of climate change for California's economy, ecosystems, and health. Designed to complement national and international studies, the project will provide California-specific but preliminary information on climate change impacts. Many efforts are already underway, and the section Research Needs describes future priorities. For example, PIER is funding a climate change research program of core research activities at UC Berkeley and UC San Diego (Scripps). Scripps is developing a comprehensive meteorological and hydrological database for the state representing historical conditions for the last 100 years. The database will be very useful for regional model inter-comparison work and the study of climatic trends. Scripps is also testing a dynamic regional climate model (Regional Spectral Model) simulating climatic conditions in California for the last 50 years a high-resolution model and they are testing new statistical downscaling techniques with the goal of capturing extreme events. Finally, they are installing meteorological and hydrological sensors in key areas/transects in California to track a changing climate and provide a richer database for future regional model enhancements and evaluations.

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1. Introduction

The issue of global climate change has begun to play an increasing role in scientific and policy debates over effective water management. In recent years, the evidence that global climate change will have significant effects on water resources in California has continued to accumulate. More than 150 peer-reviewed scientific articles on climate and water in California have now been published, with many more in preparation, addressing everything from improvements in downscaling of general circulation models to understanding how reservoir operations might be adapted to new conditions.

California water planners and managers have been among the first in the nation to consider these issues, though most efforts in this field have been both modest and informal. Initial research and analysis on climate risks facing California water resources began in the early 1980s and by the end of the decade state agencies such as the California Energy Commission had prepared the first assessments of state greenhouse gas emissions and possible impacts to a wide range of sectors. The California Water Plan (Bulletin 160) first briefly addressed climate change in 1993. More recently, the Public Interest Energy Research program (PIER) of the California Energy Commission, has reinvigorated scientific research at the state level to explore a wide range of climate impacts and risks, including risks to water resources. Other state agencies, such as the California Department of Water Resources have also revived an interest in these issues (see the Acknowledgement Section and the Research Needs summary; see also a draft summary document from PIER by Wilson et al. 2003).

In recent years, the scientific consensus has broadened that climate changes will be the inevitable result of increasing concentrations of greenhouse gases. There is also a growing consensus that various anthropogenic climate impacts are already appearing worldwide. Evidence of its impacts on California's hydrologic system has also appeared in various forms. Water agencies around the State have begun to consider the implications of climate change for the reliability and safety of water systems, and professional water organizations have begun urging managers and planners to integrate climate change into long-term planning. In 1997, the American Water Works Association issued a committee report concluding that "Agencies should explore the vulnerability of both structural and nonstructural water systems to plausible future climate changes, not just past climatic variability" and "Governments at all levels should reevaluate legal, technical, and economic approaches for managing water resources in light of possible climate changes" (AWWA 1997).

Many uncertainties remain. Responsible planning, however, requires that the California water community work with climate scientists and others to reduce those uncertainties and to begin to prepare for those impacts that are well understood, already appearing, or likely to appear. Climate change is a scientific reality. The broad consensus of the scientific community is that greenhouse gases emitted by human activities are accumulating in the atmosphere and that these gases will cause a wide range of changes in climate dynamics, especially the accumulation of terrestrial radiation (IPCC 1996, 2001; NRC 2002). Some of the most significant impacts will be on water resources – impacts that are of special concern to regions like California where water policy is already of great interest and concern (Gleick and others 2000, Wilkinson and others 2003). As concentrations of these gases continue to increase, greater amounts of terrestrial radiation will become trapped, temperatures will rise further, and other impacts will become more significant.

Substantial work has been done at the international and national level to evaluate climatic impacts, but far less information is available on regional and local impacts. This paper begins the process of summarizing some of the consequences of climate change for water resources and water systems in California. A more comprehensive assessment, supported by multiple state agencies and including the participation of a wide range of stakeholders could be a valuable tool for policymakers and planners, and we urge such an assessment to be undertaken in the near future.

2. Climate Change and Impacts on California Water Resources

Overview of Modeling

Projecting regional impacts of climatic change and variability relies first on General Circulation Models (GCMs), which develop large-scale scenarios of changing climate parameters, usually comparing scenarios with different concentrations of greenhouse gases in the atmosphere. This information is typically at too coarse a scale to make accurate regional assessments. As a result, more effort has recently been put into reducing the scale and increase the resolution of climate models through various techniques such as downscaling or integrating regional models into the global models. The resulting finer-scale output can then be analyzed for given watersheds, ideally with the incorporation of other hydrologic parameters such as local evaporation, transpiration, soil conditions, topography, snowpack, and groundwater.

Models are typically calibrated by comparing model runs over historical periods with observed climate conditions. It should be emphasized that these model results are not intended as specific predictions, but rather are scenarios based on the potential climatic variability and change driven by both natural variability and human-induced changes. Nonetheless, they are useful for assessing potential possible future conditions.

Temperature

Modeling results from GCMs are consistent in predicting increases in temperatures globally with increasing concentrations of atmospheric greenhouse gases resulting from human activity. Higher temperatures are of particular interest and concern for California water systems because of their effect on Sierra snowpack accumulation and snowmelt and other hydrologic variables, addressed below. Recent work by Snyder et al (2002) has produced the finest-scale temperature and precipitation estimates to date. Resulting temperature increases for a scenario of doubled CO₂ concentration are 1.4-3.8 degrees C throughout the region (Figure 1). This is consistent with the global increases predicted by the Intergovernmental Panel on Climate Change (2001). Sample temperature results from two different GCMs are also presented below in Figures 2a,c. In a regional model of the Western United States, Kim et al (2002) project a climate warming of around 3 to 4 degrees C. Of note in both studies is the projection of uneven distribution of temperature increases. For example, regional climate models show the warming effects are greatest in the Sierra Nevada Mountains, with implications for snowpack and snowmelt (Kim et al. 2002, Snyder et al. 2002). Similar results have been noted in Barnett et al. (2003).

Precipitation

In general, while modeling of projected temperature changes is broadly consistent across most modeling efforts, there are disagreements about precipitation estimates. Considerable uncertainties about precise impacts of climate change on California hydrology and water resources will remain until we have more precise and consistent information about how precipitation patterns, timing, and intensity will change. Some recent regional modeling efforts conducted for the western United States indicate that overall precipitation will increase (Giorgi et al. 1994, Kim et al. 2002, Snyder et al. 2002), but considerable uncertainty remains due to differences among larger-scale GCMs (Figure 1 and 2). Where precipitation is projected to increase, the increases are centered in Northern California (Kim et al. 2002, Snyder et al. 2002, Figure 1) and in winter months. More general large-scale precipitation results from two different GCMs are also presented below in Figures 2b,d. Further work is in progress to extend and improve these modeling efforts, and to use watershed-scale hydrological models that will be of more direct value to planners.

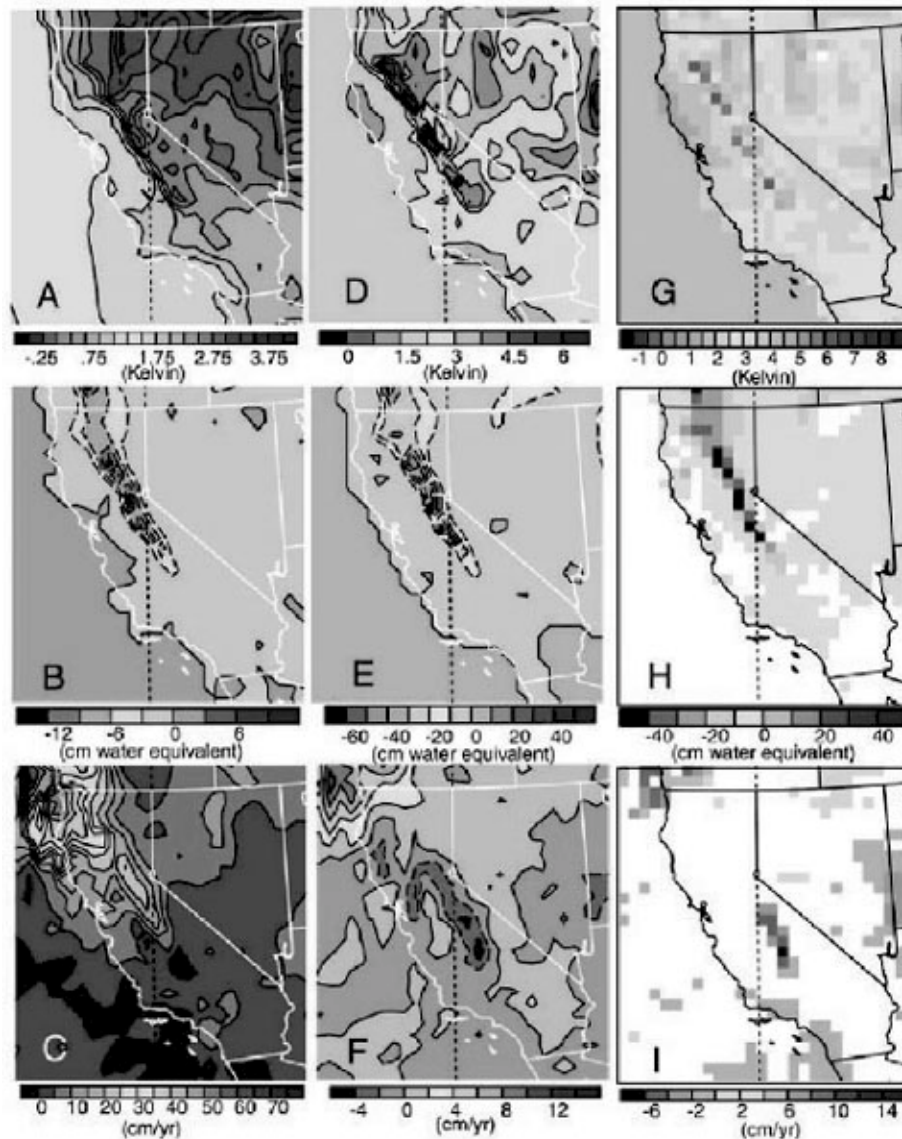


Figure 1. Comparison of modeling results for a baseline CO₂ scenario (column 1) and doubled CO₂ scenario (column 2). Column 3 shows the differences between the two scenarios. Panels A, D, and G compare modeled surface temperatures throughout the California region as represented in the model of Snyder et al. (2002). The temperature increases of 1.4-3.8 degrees C throughout the region are consistent with global modeling projections. Panels B, E, and H represent changes in April snowpack, and show a statistically significant decrease in the Sierras. Panels C, F and I show April precipitation. Note the increase in the northern part of the State, and slight decrease central California. Figure from Snyder et al. (2002).

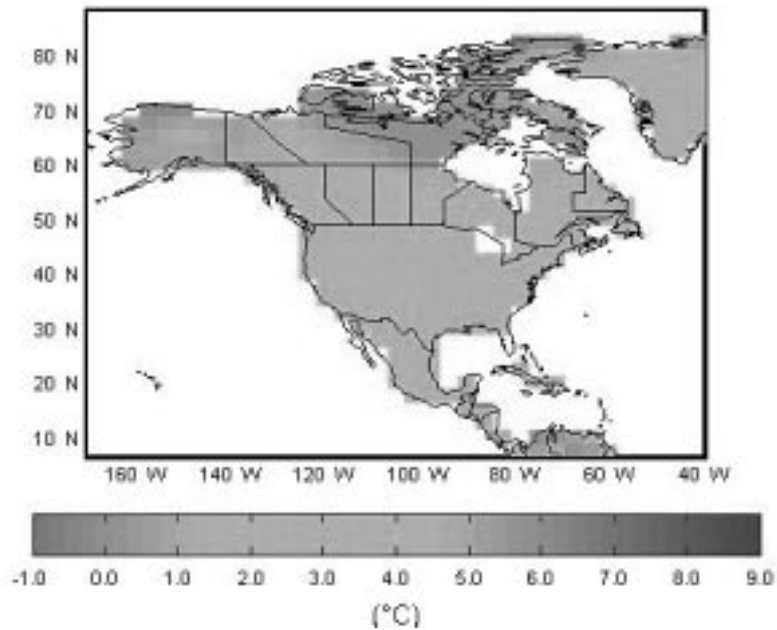


Figure 2a: Hadley2 model temperature changes for 2080 showing increases of 2 to 5 degrees C for the western United States.
www.cics.uvic.ca/scenarios/index.cgi

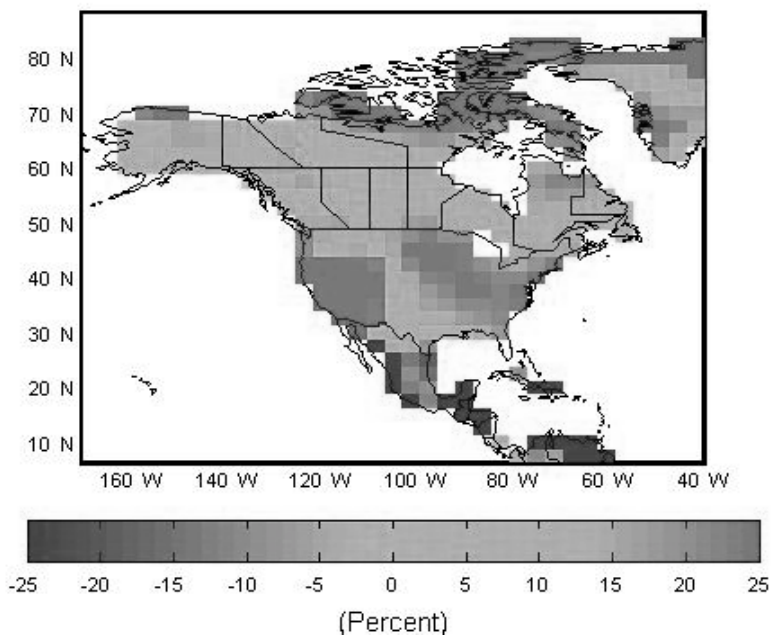


Figure 2b: Hadley2 model precipitation changes for 2080, showing projected increases in precipitation in the western United States.
www.cics.uvic.ca/scenarios/index.cgi

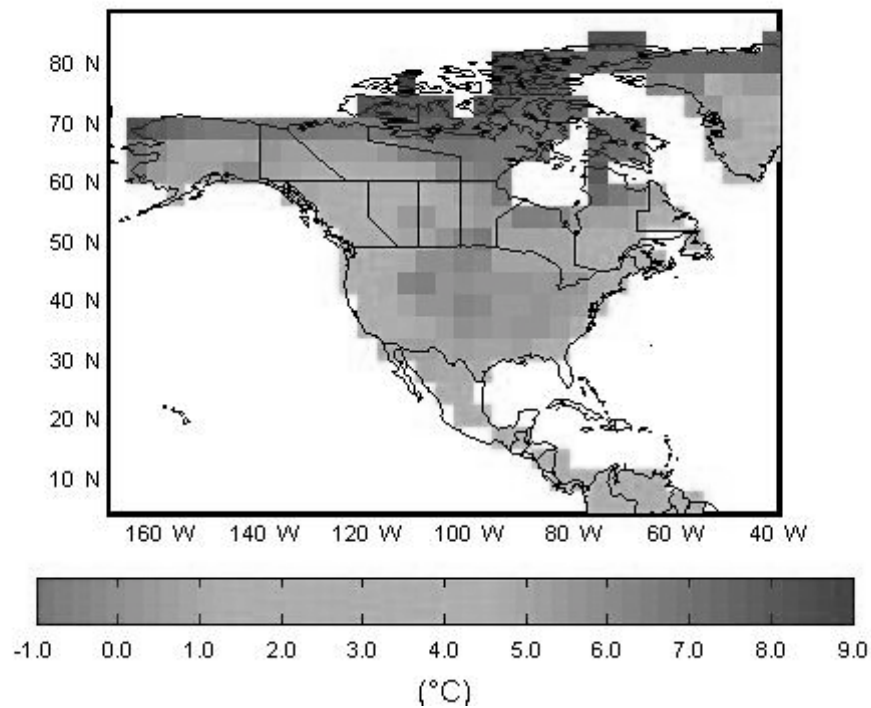


Figure 2c: Canadian model 1 showing temperature changes across North America for 2080, including 3 to 7 degrees C temperature increases in the western United States. www.cics.uvic.ca/scenarios/index.cgi

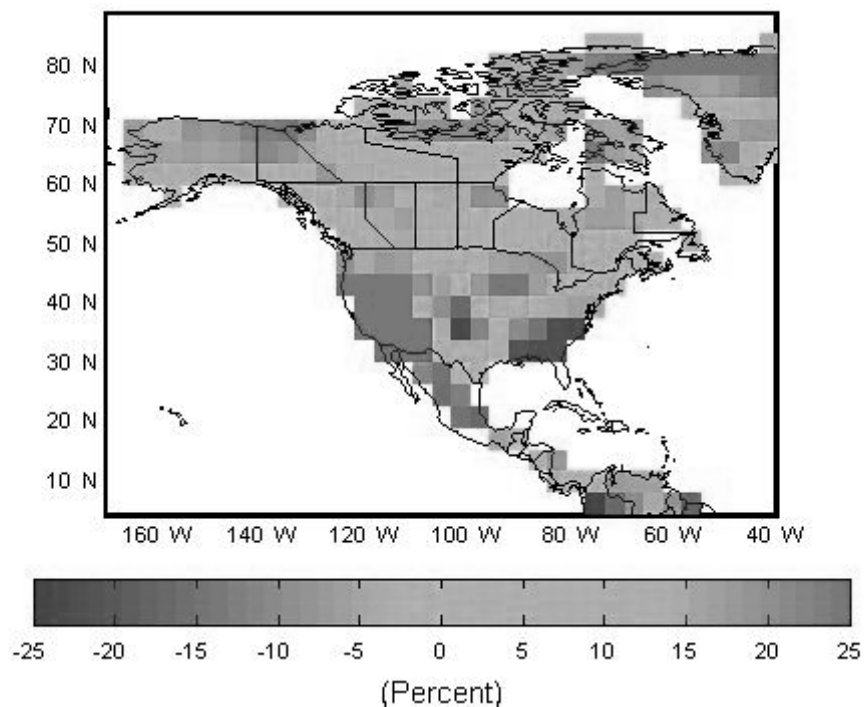


Figure 2d: Canadian climate model precipitation changes for 2080 showing substantial precipitation increases in the western United States. www.cics.uvic.ca/scenarios/index.cgi

Evaporation and Transpiration

Evaporation and transpiration are important aspects of the hydrologic balance affecting climate, plant growth and distributions, and water demand and use. Increasing average temperatures generally lead to an increase in the potential for evaporation, though actual evaporation rates are constrained by the water availability on land and vegetation surfaces and in the soils. In California, atmospheric moisture content can limit evaporation rates, so changes in humidity are relatively important. Vegetative cover is also important because plants intercept precipitation and transpire water back to the atmosphere. Different vegetation types play different roles in evaporation; so evaluating the overall hydrologic impacts of climate change in a region requires some understanding of current vegetation patterns and of the ways in which vegetation patterns may change.

Transpiration, the movement of water through plants to the atmosphere, is affected by variables including plant cover, root depth, stomatal behavior, and the concentration of carbon dioxide in the atmosphere. Investigations of the impacts of increased carbon dioxide concentrations on transpiration have yielded conflicting results – some assessments suggest reductions in overall water use while others indicate that some plants acclimatize to increased CO₂ levels, limiting improvements in water-use efficiency (Field et al. 1995, Korner 1996, Rötter and Van de Geijn 1999). Multiple factors related to climate change can have more complex effects when taken together, including suppressing gains in plant growth. (Shaw et al 2002). Reproducible generalizations for evapotranspiration (ET) are not yet available, and these issues are central for future research.

Climate models have consistently projected that global average evaporation would increase in the range of 3 to 15 percent for an equivalent doubling of atmospheric carbon dioxide concentration. The greater the warming, the larger these increases are expected to be (IPCC 2001).

Snowpack

By delaying runoff from winter months when precipitation is greatest, snow accumulation in the Sierra Nevada acts as a massive natural reservoir for California. Despite uncertainties about how increased greenhouse gas concentrations may affect precipitation, there is very high confidence that higher temperatures will lead to dramatic changes in the snowfall and snowmelt dynamics in watersheds with substantial snow (see summary in Gleick and others 2000). Higher temperatures will have several major effects: they will increase the ratio of rain to snow, delay the onset of the snow season, accelerate the rate of spring snowmelt, and shorten the overall snowfall season, leading to more rapid and earlier seasonal runoff.

As early as the mid-1980s and early 1990s, regional hydrologic modeling of global warming impacts has suggested with increasing confidence that higher temperatures will affect the timing and magnitude of runoff in California (see, for example, Gleick 1986, Gleick 1987a,b, Lettenmaier and Gan 1990, Lettenmaier and Sheer 1991, Nash and Gleick 1991a,b, Hamlet and Lettenmaier 1999). Indeed, over the past two decades, this has been one of the most persistent and well-established findings on the impacts of climate change for water resources in the United States and elsewhere, and it continues to be the major conclusion of regional water assessments (see, for example, Knowles and Cayan 2002, Barnett et al. 2003). Figure 3 shows hypothetical changes in hydrographs that can be expected with changing snow dynamics in the Sierra Nevada. Figure 4 shows a specific projection of changes in Sierra Nevada snowpack from a regional modeling study.

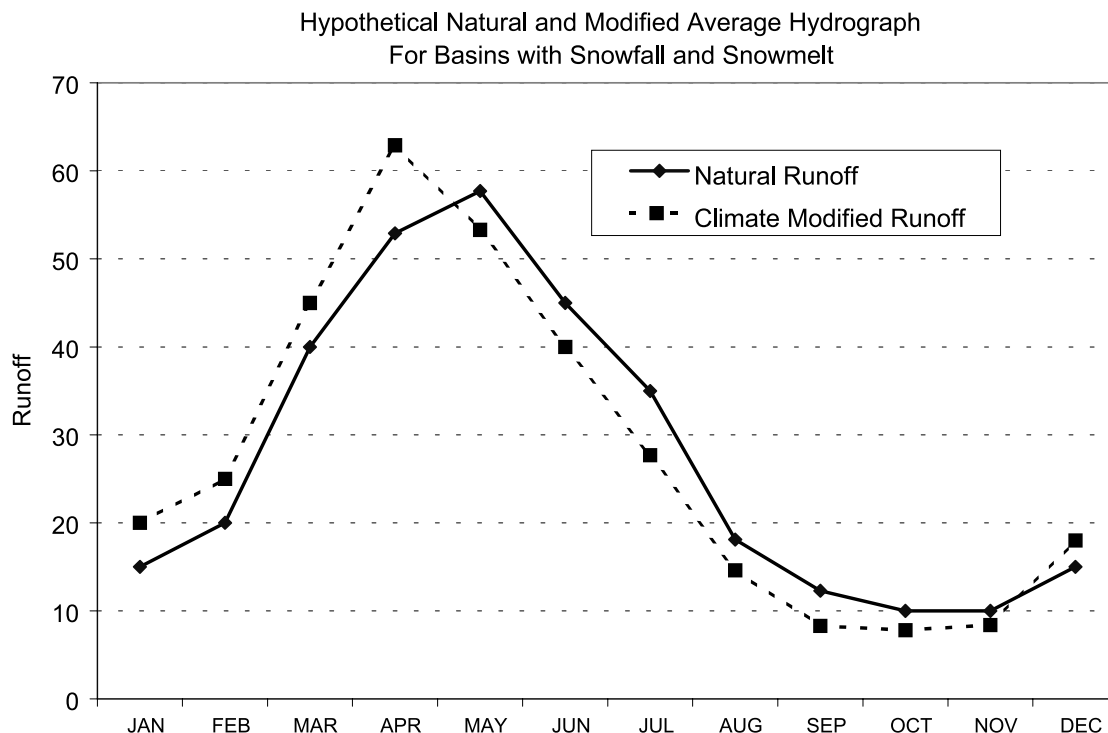


Figure 3: Rising temperatures will reduce runoff in spring and summer and increase it during winter months by affecting snowfall patterns and the timing and rate of snowmelt. (from Gleick and others 2000).

A few broad assessments have simulated the effects of climate change on snowpack in the United States (McCabe and Legates 1995, Cayan 1996, McCabe and Wolock 1999). McCabe and Wolock (1999) evaluated the links between climate conditions and snowpack for over 300 different snow sites in the western U.S., including the Sierra Nevada and the Colorado basin. They used long-term historical records to develop a snow model that used altered climatic information from GCMs. For most of the sites, strong positive correlations were found between precipitation and snowpack; strong negative correlations were found between temperature and snowpack. These correlations indicate that the supply of winter moisture is the best predictor of snowpack volume, while temperature is the best predictor of the timing of snowmelt and the overall nature of the snow season. This correlation breaks down only for those high-altitude sites where mean winter temperatures are so cold that the ratio of rain to snow is not affected.

The models used in the National Assessment (Gleick and others 2000) show large decreases in April 1 snowpack for all of the snow sites in California. In some of the extreme cases, model snowpack is completely eliminated by the end of the next century, although some snowfall and snowmelt would certainly continue in high-altitude sites. More recent work with a more detailed regional scale shows snow accumulation in February will be reduced by up to 82% in a 2xCO₂ scenario, with an almost complete melting by the end of April (Snyder et al. 2002). Figures 1 and 4 show other modeling efforts projecting that decreased snowfall and enhanced winter snowmelt could deplete most of the snow cover in California by the end of the winter (Kim et al. 2002, Knowles and Cayan 2002).

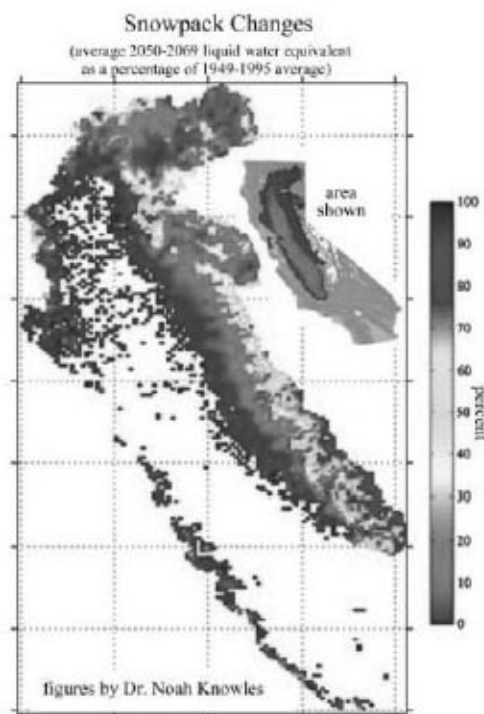


Figure 4: Possible snowpack changes from Knowles and Cayan (2002) for the Sierra Nevada, showing dramatic drops in snowpack liquid water content by the middle of this century for typical GCM projections of temperature increases. This dramatic graphic is a good illustration of the kinds of snowpack changes noted in a wide range of studies beginning in the early 1980s (see text for details).

Variability, Storms, and Extreme Events

Variability is a natural part of any climatic system, caused by processes that will continue to exert an important influence on the climate system even as changes induced by rising concentrations of greenhouse gases are felt. Efforts to understand how natural patterns of variability, such as hurricanes, intense rainstorms, and El Niño/La Niña events affect California's water resources help to identify vulnerabilities of existing systems to hydrologic extremes (McCabe 1996, Vogel et al 1997, Piechota et al. 1997, Cayan et al. 1999).

Large climatic variability has been a feature of California's past. Paleoclimatic evidence from tree rings, buried stumps, and lakebed sediment cores suggests that the past 200 years has been relatively wet, and relatively constant when compared with longer records (Meko et al. 1980; Michaelsen et al. 1987; Hughes and Brown 1992; Earle 1993; Haston and Michaelsen 1997; Meko et al. 2001; Benson et al. 2002). These longer records reveal greater variability than the historical record, in particular in the form of severe and prolonged droughts (Stine 1994). In spite of this evidence, planning and operation are generally based on the historical climate record since 1900, which may not be representative of past or future conditions.

While variability is not well modeled in large-scale general circulation studies, some modeling studies suggest that the variability of the hydrologic cycle increases when mean precipitation increases, possibly

accompanied by more intense local storms and changes in runoff patterns (Noda and Tokioka 1989; Kothavala 1997; Hennessy et al. 1997). In addition, another long-standing model result points to an increase in drought often resulting from a combination of increased temperature and evaporation along with decreased precipitation (Haywood et al. 1997; Wetherald and Manabe 1999, Meehl et al. 2000, Lambert 1995, Carnell and Senior 1998, Felzer and Heard 1999).

Models produce various pictures of increased storminess, but increased storm intensity is consistently forecast, whether or not their frequency also increases. (Carnell and Senior 1990, Hayden 1999, Lambert 1995, Frei et al. 1988)

The frequency of El Niño events may increase due to greenhouse warming. Timmermann et al. (1999) used a high-resolution global climate model to simulate the El Niño/Southern Oscillation phenomenon (ENSO) under conditions of warming. Their model indicated that the tropical Pacific climate system would undergo systematic changes if greenhouse gas concentrations doubled. In particular, their results suggest a world where the average condition is like the present-day El Niño condition and events typical of El Niño will become more frequent. Their results also found more intense La Niña events and stronger interannual variability, meaning that year-to-year variations may become more extreme under enhanced greenhouse conditions. More frequent or intense El Niños would alter precipitation and flooding patterns in the United States in a significant way.

In a study that analyzed 20 GCMs currently in use worldwide, extreme events may intensify over the next century as carbon dioxide and other greenhouse gases increase in the atmosphere. The study concludes that the West Coast will probably be less affected because of its heavier rainfall and more moist soil (Meehl and Easterling 2001). In a study that reviewed several GCM scenarios an increased risk of large storms and flood events was shown for California (Miller and Dettinger 1999). Conflicting conclusions about storms support the need for higher-spatial-resolution models with better cloud and precipitation processes.

Major floods on California's rivers are produced by slow moving Pacific storm systems, which sweep moist subtropical air from a southwesterly direction into the State. In modeling by DWR on the American River basin, increased storm temperatures of three degrees Celsius increased storm runoff by about 10 percent (personal communication, M. Roos 2003). The 1986 flood on which these experiments were based had the highest 3-day average flow on record for the American River, claimed fifteen lives, and caused more than a billion dollars in property damage (www.news.water.ca.gov/1997.spring/quest.html). Since existing flood control facilities in the Central Valley and elsewhere can barely accommodate such a large flood event, even a modest increase caused by climate warming could pose problems without either changes in operations or infrastructure.

Large-Area Runoff

Runoff is directly affected by changes in precipitation and temperature. However, runoff in actual watersheds is rarely explicitly evaluated in GCMs because their resolution is insufficient to include other critical watershed characteristics. Estimates of changes in runoff over large areas are thus often relatively simple evaluations of changes in large-scale precipitation and evapotranspiration patterns (Arnold et al. 1998, Arnold et al. 1999, Srinivasan et al. 1993). Despite remaining uncertainties in precipitation patterns, especially, Brown et al. (1999) concluded that the potential impact of altered precipitation and the

expected increases in evapotranspiration are of large enough dimensions to require consideration in any analysis of future regional or national water supply and demand. Another important consideration is the projected change in seasonality of the hydrologic cycle that would affect the heavily managed water systems of the western U.S.

In California, water yields will increase in late winter/early spring because of increased runoff, as described earlier, due to the seasonality of the precipitation changes and to an earlier spring snowmelt caused by the projected warming under climate change. Rising temperatures also impact annual water yields by increasing ET, thereby reducing the contribution of lateral flow to streamflow and groundwater recharge. This combination results in a marked increase in water yield during late winter and early spring and in some cases a reduction in water yield during the summer. If there is no general increase in precipitation in these regions the early snowmelt will lead to shortages of water in summer. The hydrology is controlled by the timing and intensity of the spring snowmelt, and is impacted principally by the degree of warming during this time period.

Several different conclusions can be drawn from a review of the literature. First, the great differences in results show the difficulty of making accurate “predictions” of future runoff – these results should be viewed with as sensitivity studies and used with considerable caution. Second, runoff is extremely sensitive to climate conditions. Large increases in precipitation will probably lead to increases in runoff: such increases can either worsen or lessen water management problems, depending on the region and the nature of the problem. Third, far more work is needed, on a finer scale, to understand how climate will affect national water resources. Until GCMs get better at evaluating regional temperature and precipitation, their regional estimates of future runoff must be considered speculative and uncertain. While it is well established that changes in runoff are likely to occur, we have little confidence that we understand how specific regions will be affected. The above discussion and model results highlight many of the uncertainties surrounding the implications of climate change for overall water availability.

Regional Runoff

Detailed estimates of changes in runoff due to climate change been produced for California using regional hydrologic models. By using anticipated, hypothetical, or historical changes in temperature and precipitation and models that include realistic small-scale hydrology, modelers have consistently seen significant changes in the timing and magnitude of runoff resulting from quite plausible changes in climatic variables. In California, runoff is extremely sensitive to rainfall: a small percentage change in rainfall can produce a much larger percentage change in runoff. Considerable effort has been made to evaluate climate impacts in particular river basins, including the Sacramento, the San Joaquin, the Colorado, the Carson/Truckee, and others. Even in the absence of changes in precipitation patterns, higher temperatures resulting from increased greenhouse gas concentrations lead to higher evaporation rates, reductions in streamflow, and increased frequency of droughts (Schaake 1990, Rind et al. 1990, Nash and Gleick 1991a,b, 1993). In such cases, increases in precipitation would be required to maintain runoff at historical levels.

For California, one of the most important results for planners has also been one of the most consistent. Warming-induced change in the timing of streamflow, including both the intensity and timing of peak flows is a consistent result. A declining proportion of total precipitation falls as snow as temperatures rise, more winter runoff occurs, and remaining snow melts sooner and faster in spring (see, for example,

Gleick 1986, 1987a,b, Lettenmaier and Gan 1990, Nash and Gleick 1991b, Miller et al. 1992, Knowles and Cayan 2002, Van Rheeën et al. 2003). In some basins, spring peak runoff may increase; in others, runoff volumes may significantly shift to winter months.

Shifts in runoff timing in snowmelt-fed basins are consistent in all studies that looked at daily or monthly runoff. These studies show with very high confidence that increases in winter runoff, decreases in spring and summer runoff, and higher peak flows will occur in such basins as temperatures rise. With warming, snow levels in the mountains will rise on average, and the average amount of snow covered area and snowpack will decrease. A reasonable estimate is about 500 feet of elevation change for every degree Celsius rise (M. Roos, personal communications).

Assuming the amount of precipitation remained approximately the same, in the Sacramento River region, only about one fourth of the snow zone would remain with an estimated decrease of 5 MAF of April through July runoff (Cayan 1996, Knowles and Cayan 2002, Miller and Dettinger 1999). The impact would be much less in the higher elevation of southern Sierra. For example in the San Joaquin/Tulare Lake region about seven-tenths of snow zone would remain.

Under current operating rules, less spring snowmelt could also make it more difficult to refill winter reservoir flood control space during late spring and early summer of many years, thus potentially reducing the amount of surface water available during the dry season. Lower early summer reservoir levels also would adversely affect lake recreation and hydroelectric power production, with possible late-season temperature problems for downstream fisheries. Not all river systems would be equally affected; much depends on the existing storage capacity. The storage-to-runoff ratio for the American River is only about 0.64, which makes it more vulnerable to these changes than, for example, the Stanislaus River with a ratio of 2.45.

Colorado River

The Colorado River supplies water to nearly 30 million people and irrigates more than one and a half million hectares of farmland in Wyoming, Colorado, Utah, New Mexico, Arizona, Nevada, California, and the Republic of Mexico. Spanning 2,300 kilometers and eventually running through Mexico to the Sea of Cortez, the river is the only major water supply for much of the arid southwestern United States and the Mexicali Valley of Mexico, and it plays a special role in California's water situation.

Colorado River basin water supply, hydroelectricity generation, reservoir levels, and salinity are all sensitive to both the kinds of climate changes that are expected to occur and to the policy options chosen to respond to them. Because of concerns about these issues, some of the very first river basin climate studies examined the impacts of climatic changes on the Colorado River basin and several of its major tributaries.

The earliest studies used historical regression approaches to evaluate the impacts of hypothetical temperature and precipitation changes (Stockton and Boggess 1979 and Revelle and Waggoner 1983). Both of these studies suggested that modest changes in average climatic conditions could lead to significant changes in runoff. Revelle and Waggoner concluded that a 2 degree Celsius (C) increase in temperature with a 10-percent drop in precipitation would reduce runoff by 40 percent. Stockton and Boggess' results were similar, with a projected 35 to 56 percent drop in runoff.

By the late 1980s, researchers began to use physically based models capable of evaluating climatic conditions outside of the range of existing experience and hydrologic statistics. Under the auspices of the American Association for the Advancement of Science (AAAS), Schaake (1990) used a simple water-balance model to evaluate the elasticity of runoff in the Animas River in the upper Colorado River basin. That study suggested that a 10-percent change in precipitation would lead to a 20-percent change in runoff, while a 2 degree C increase in temperature would reduce runoff by only about 2 percent. More significant, however, was the finding that changes in temperature would have significant seasonal effects on snowmelt, a finding in agreement with the earlier conclusions of Gleick (1987) for the Sacramento River (described elsewhere).

In 1991, the U.S. Bureau of Reclamation, which has responsibility for operations in the Colorado Basin, and the U.S. Geological Survey, evaluated the impacts of global climate change on the Gunnison Basin, an important tributary of the Colorado. Like the earlier Schaake study, this analysis also found significant seasonal changes in runoff due to increases in temperature, with an advance in spring snowmelt of close to a month for a temperature increase of 2 to 4 degrees C (Dennis 1991).

Nash and Gleick (1991a,b, 1993) analyzed the impacts of climate change on the Colorado basin using conceptual hydrologic models coupled with the U.S. Bureau of Reclamation Colorado River Simulation System (CRSS) model of the entire water-supply system of the river (Nash and Gleick, 1991a,b, 1993). They evaluated hypothetical temperature and precipitation scenarios as well as the equilibrium GCM scenarios available at the time. A GCM transient run was done as well with one of the first models to use transient greenhouse gas inputs. River flows were found to be very sensitive to both precipitation and temperature, though less sensitive than the earlier regression studies. As with earlier studies, major changes in the seasonality of runoff resulted from the impacts of higher temperature on snowfall and snowmelt dynamics. The effects of climate changes on water supplies were dependent on the operating characteristics of the reservoir system and the institutional and legal rules constraining the operators. The variables most sensitive to changes in runoff were found to be salinity, hydroelectric generation, and reservoir level. This study also evaluated the possible utility of increased storage capacity to address the impacts of climate changes and concluded that additional storage would do nothing to alleviate potential reductions in flow. Only if climatic changes were to increase streamflow variability without decreasing long-term supply might additional reservoirs in the Upper Colorado River Basin have any benefits.

Another comprehensive assessment of the Colorado Basin's systems of reservoirs was done for the Colorado River Severe Sustained Drought study (CRSSD) (Lord et al.1995). That analysis focused on a scenario of long-term drought, rather than a single climate change scenario, and concluded that the "Law of the River" as currently implemented would leave ecosystems, hydropower generation, recreational users, and Upper Basin water users vulnerable to damages despite the extensive infrastructure. A related study also found that water reallocation through marketing had the power to reduce drought damages (Booker 1995).

Eddy (1996) looked at extreme events in the Colorado Basin and evaluated the impact of an increase or decrease in precipitation of 10 percent on the duration of wet and dry periods. Eddy concluded that changing average precipitation would not change the number of consecutive wet or dry years by more than one year, but that about once every 20 years, some groupings of stations would experience a

dramatic change in consecutive extreme years. If several portions of the Upper Colorado Basin experienced these major wet or dry periods simultaneously, “an episode of crisis proportions could occur.” Recently, Christensen et al. (2002) have updated this work on the Colorado River basin and found comparable changes in snowfall/snowmelt dynamics, runoff, and sensitivity of the water resource system in the basin to climate change.

Soil Moisture

Soil moisture – a measure of the water in different depths of soil – defines vegetation type and extent, influences agricultural productivity, and affects groundwater recharge rates. The amount of water stored in the soils is influenced by vegetation type, soil type, evaporation rates, and precipitation intensity. Any changes in precipitation patterns and evapotranspiration regime directly affect soil-moisture storage. Decreased precipitation or increased temperature can each lead to decreases in soil moisture. Where precipitation increases significantly, soil moisture is likely to increase, perhaps by large amounts.

GCM results suggest large-scale regional soil drying in summer owing to higher temperatures. Drying could have significant impacts on agricultural production and on the supply of and demand for water. One consequence of this is an expected increased incidence of droughts in some regions, measured by soil-moisture conditions, even where precipitation increases, because of the increased evaporation (Vinnikov et al. 1996). Soil-moisture response has important implications for crop yield and irrigation demand (Brumelow and Georgakakos 2000).

Modeling of the Sacramento Basin identified reductions in summer soil moisture of 30 percent or more resulting from a shift in the timing of runoff from spring to winter, a decrease in snow, and higher summer temperatures and evaporative losses (Gleick 1986, 1987a,b). Similar results are seen for the Colorado River basin, where large increases in precipitation were found to be necessary in order to simply maintain soil moisture at present historical levels as temperatures and evaporative losses rise (Nash and Gleick 1991b, 1993).

Water Quality

Water quality depends on a wide range of variables, including water temperatures, flows, runoff rates and timing, and the ability of watersheds to assimilate wastes and pollutants. Climate change could alter all of these variables. Higher winter flows of water could reduce pollutant concentrations or increase erosion of land surfaces and stream channels, leading to higher sediment, chemical, and nutrient loads in rivers. Changes in storm flows will affect urban runoff, with attendant water-quality impacts. Lower summer flows could reduce dissolved oxygen concentrations, reduce the dilution of pollutants, and increase zones with high temperatures. Less directly, changes in land use resulting from climatic changes, together with technical and regulatory actions to protect water quality, can be critical to future water conditions. The net effect on water quality for rivers, lakes, and groundwater in the future therefore depends not just on how climatic conditions might change but also on a wide range of other human actions and management decisions, as noted in modeling experiments by Earhart et al. (1999).

In a review of potential impacts of climate change on water quality, Murdoch et al. (2000) conclude that significant changes in water quality are known to occur as a direct result of short-term changes in climate. They note that water quality in ecological transition zones and areas of natural climate extremes is vulnerable to climate changes that increase temperatures or change the variability of precipitation and

argue that changes in land and resource use will have comparable or even greater impacts on water quality than changes in temperature and precipitation. They recommend that long-term monitoring of water quality is critical for identifying severe impacts, as is developing appropriate management strategies for protecting water quality.

Moore et al. (1997) note that increased water temperatures enhance the toxicity of metals in aquatic ecosystems and that increased lengths of biological activity could lead to increased accumulation of toxics in organisms. Ironically, increased bioaccumulation could decrease the concentration of toxics in the water column, improving local water quality. Similarly, higher temperatures may lead to increased transfer of chemicals from the water column to sediments. However, increases in air temperature, and the associated increases in water temperature, are likely to lead to adverse changes in water quality, even in the absence of changes in precipitation.

Ecosystems influence water quality in very direct ways. Changes in terrestrial ecosystems will also lead to changes in water quality by altering nutrient cycling rates and the delivery of nutrients to surface waters (Murdoch et al. 1998). The issues of water quality and ecosystem health should be weighed together (see below).

Studies suggest that changes in precipitation will affect water quantity, flow rates, and flow timing. Decreased flows can exacerbate temperature increases, increase the concentration of pollutants, increase flushing times, and increase salinity (Schindler 1997, Mulholland et al. 1997). Decreased surface-water volumes can increase sedimentation, concentrate pollutants, and reduce non-point source runoff (Mulholland et al. 1997). Increases in water flows can dilute point-source pollutants, increase loadings from non-point source pollutants, decrease chemical reactions in streams and lakes, reduce the flushing time for contaminants, and increase export of pollutants to coastal wetlands and deltas (Jacoby 1990, Mulholland et al. 1997, Schindler 1997). Higher flows can increase turbidity in lakes, reducing UV-B penetration. More work specific to California needs to be done.

Lake Levels and Conditions

Although little California-specific work has been done, lakes are known to be sensitive to a wide array of changes in climatic conditions. Variations in temperature, precipitation, humidity, and wind conditions can alter evaporation rates, the water balance of a basin, ice formation and melting, and chemical and biological regimes (McCormick 1990, Croley 1990, Bates et al. 1993, Hauer et al. 1997, Covich et al. 1997, Grimm et al. 1997, Melak et al. 1997). Closed (endorheic) lakes are extremely sensitive to the balance of inflows and evaporative losses. Even small changes in climate can produce large changes in lake levels and salinity (Laird et al. 1996).

Other effects of increased temperature on lakes could include higher thermal stress for cold-water fish, higher trophic states leading to increased productivity and lower dissolved oxygen, degraded water quality and increased summer anoxia. Decreases in lake levels coupled with decreased flows from runoff and groundwater may exacerbate temperature increases and loss of thermal refugia and dissolved oxygen. Increased net evaporation may increase salinity of lakes. Hostetler and Small (1999) also note that climate variability may amplify or offset changes in the mean state under climate changes and may ultimately be more important than changes in average conditions. Some non-linear or threshold events may also occur, such as a fall in lake level that cuts off outflows or separates a lake into two isolated parts. Work is

needed to identify threatened lakes in California and projected impacts of such events on downstream flows and groundwater recharge.

Groundwater

Groundwater withdrawals in California in the mid-1990s are estimated to be around 14.5 million acre-feet, nearly 20 percent of all the groundwater withdrawn in the entire United States. (In typical years, groundwater accounts for around 30 percent of all urban and agricultural water use in the state (www.waterplan.water.ca.gov/groundwater/DraftUpdate/Chapter1.pdf). In some areas current levels of groundwater use are already unsustainable, with pumping rates exceeding natural recharge. Groundwater overdrafts in California in the drier years of the 1990s averaged nearly 1.5 million acre-feet per year (California Department of Water Resources 1998).

Little work has been done on the impacts of climate changes for specific groundwater basins, or for general groundwater recharge characteristics or water quality. Changes in recharge will result from changes in effective rainfall as well as a change in the timing of the recharge season. Increased winter rainfall, expected for some mid-continental, mid-latitude regions could lead to increased groundwater recharge. Higher temperatures could increase the period of infiltration where soils freeze. Higher evaporation or shorter rainfall seasons, on the other hand, could mean that soil deficits persist for longer periods of time, shortening recharge seasons (Leonard et al. 1999). A significant portion of winter recharge comes from deep percolation of precipitation below the rooting zone, whether of native vegetation or farmland. Warmer winter temperatures between storms would be expected to increase ET, thereby drying out the soil between storms. A greater amount of rain in subsequent storms would then be required to wet the root zone and provide water for deep percolation.

Pumping from some coastal aquifers in California has exceeded the rates of natural recharge, resulting in saltwater intrusion into the aquifers. Sea-level rise could also affect coastal aquifers through saltwater intrusion. Oberdorfer (1996) used a simple water-balance model to test how changes in recharge rates and sea-level would affect groundwater stocks and flows in a California coastal watershed. While some sensitivities were identified, the author notes that the complexity of the interactions among the variables required more sophisticated analysis.

Warmer, wetter winters would increase the amount of runoff available for groundwater recharge. However, this additional runoff in the winter would be occurring at a time when some basins, particularly in Northern California, are either being recharged at their maximum capacity or are already full. Conversely, reductions in spring runoff and higher evapotranspiration because of higher temperatures could reduce the amount of water available for recharge. The extent to which climate will change and the impact of that change are both unknown. A reduced snowpack, coupled with increased rainfall may require a change in the operating procedures for our existing dams and conveyance facilities.

The most recent California groundwater report from the Department of Water Resources notes that these possible changes may require more sophisticated conjunctive management programs in which the aquifers are more effectively used as storage facilities. They also recommend that water managers consider evaluating their systems to better understand the existing snowpack-surface water-groundwater relationship, and identify opportunities that may exist to optimize groundwater storage capability under

new hydrologic regimes that may result from climate change. Visit www.waterplan.water.ca.gov/groundwater/DraftUpdate/Chapter1.pdf.

Sea Level

Sea-level rise, caused by thermal expansion of ocean waters and melting of ice from land surfaces, will affect groundwater aquifers and coastal ecosystems. Mean sea level (msl) data for stations along the coast of California show msl rising. Figures 5a and b show the increase as measured at Fort Point/the Golden Gate in San Francisco over the past 100 years. Early studies of the impacts of sea-level rise in California show that estuarine impacts of sea-level rise will be felt in the San Francisco Bay and the Sacramento-San Joaquin River delta in northern California (Williams 1985, 1987, SFBCDC 1988). Among the risks will be threats to levee integrity and tidal marshes, the salinity of water in the Delta region, and intrusion of salt water into coastal aquifers.

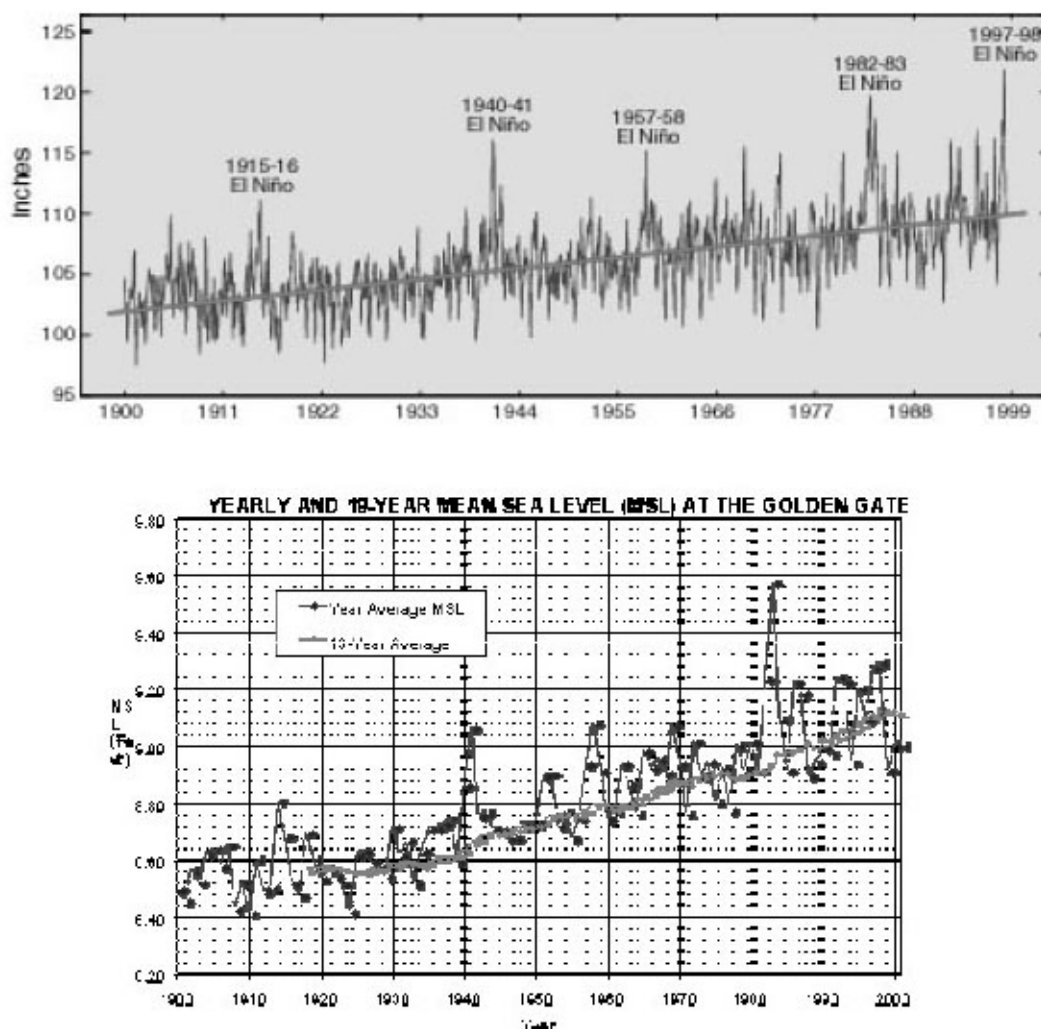


Figure 5a and b: Yearly and mean sea-level rise at the Golden Gate, California, from 1900. Sea level rise at Fort Point, San Francisco. This is the longest continuous record of sea level rise on the west coast of the United States. Source: The U.S. Geological Survey, <http://geopubs.wr.usgs.gov/fact-sheet/fs175-99/>.

Delta levees protect transportation systems, agriculture, and homes in the region. Williams projected that levees would fail at a higher rate, sediment movements would be changed, mudflats and salt marshes would experience more erosion, and ecosystem impacts could be substantial (Williams 1985, 1987). In addition, tidal marshes in parts of the San Francisco Bay would be submerged by a one-meter sea-level rise (SFBCDC 1988). One analysis showed that only a 15-centimeter (6 inch) rise would transform the current 100-year high tide peak in San Francisco Bay into about a 10-year event (Gleick and Mauer 1990). Severe high tides could thus become a more frequent threat to the delta levees and their ability to protect land and water systems there.

Williams (1985, 1987) also concluded that the average salinity level could migrate roughly 15 kilometers upstream, impacting the State's water-supply infrastructure. This could degrade fresh water transfer supplies pumped at the southern edge of the Delta or require more fresh water releases to repel ocean salinity. Salinity is already a problem in the Delta. Both the Central Valley Project and the State Water Project are operated under water quality constraints. Most of the time, salinity constrains the project operations in late summer and early fall when the availability of water in the reservoirs are at its lowest. Therefore, to mitigate an increase in salinity due to sea level rise pumping has to be cut during these months. The project operations are further constrained by X2 standards in months of February through June. (X2 is the distance in kilometers of tidally and depth averaged 2 psu isohaline from the Golden Gate bridge.) More reservoir releases or reduced pumping would be required to push the increased salinity intrusion caused by the sea level rise back towards the bridge.

Earlier snowmelt runoff in the spring would allow more time for summer saltwater intrusion. Preliminary modeling studies indicate that increase in sea level and changes in freshwater inflows would affect salinity throughout the Sacramento-San Joaquin Delta (see, for example, Knowles and Cayan 2002).

Ecosystems

Humans are dependent upon ecosystem processes to supply essential goods and services such as primary productivity and inputs from watersheds, fish for commercial and recreational purposes, decomposition and biological uptake, and water purification. The health and dynamics of ecosystems are fundamentally dependent on a wide range of climate-sensitive factors, including the timing of water availability, overall water quantity, quality, and temperature. All of these factors may be altered in a changed climate. Freshwater systems are rich in biological diversity, and a large part of the fauna is threatened in California – 150 species of animals are listed as endangered or threatened under state and federal law, and more than 200 species of plants are facing similar threats (www.dfg.ca.gov/hcpb/species/t_e_spp/tespp.shtml). A changing climate may intensify these threats in many ways, such as by accelerating the spread of exotic species and further fragmenting populations (Firth and Fisher 1991, Naiman 1992). Experience with ecosystem dynamics strongly suggests that perturbing ecosystems in any direction away from the conditions under which they developed and thrive will have adverse impacts on the health of that system (Peters and Lovejoy 1992, IPCC 2001).

The direct effects of climate change on ecosystems will be complex. Previous assessments have established a wide range of possible direct effects, including changes in lake and stream temperatures, lake levels, mixing regimes, water residence times, water clarity, thermocline depth and productivity, invasions of exotic species, fire frequency, permafrost melting, altered nutrient exchanges, food web structure, and more (for a review see Gleick and others 2000, Wilkinson and others 2003).

The ecological response to a modification in natural flow regime resulting from climate change depends on how the regime is altered relative to the historical conditions (Meyer et al. 1999). For example, a system that has historically experienced predictable, seasonal flooding, such as snowmelt-dominated streams and rivers, may show dramatic changes in community composition and ecosystem function if the seasonal cycles are eliminated or substantially altered, as has been documented for the loss of riparian trees along western watercourses (Auble et al. 1994).

It is likely that the ecosystems at greatest risk from climate change are those that are already near important thresholds, such as where competition for water is occurring, where water temperatures are already near limits for a species of concern, or where climate change will act with other anthropogenic stressors such as large water withdrawals or wastewater returns (Meyer et al. 1999, Murdoch et al. 2000).

There will be both positive and negative direct effects of increasing temperatures on aquatic and terrestrial ecosystems. In general, while many uncertainties remain, ecologists have high confidence that climatic warming will produce a northward shift in species distributions, with extinctions and extirpations of temperate or cold-water species at lower latitudes, and range expansion of warm-water and cool-water species into higher latitudes (Murdoch et al. 2000).

If California water temperatures rise significantly, the difficulty of managing the state's already threatened salmon and steelhead fisheries would increase. Higher atmospheric temperatures will make it more difficult to maintain rivers cold enough for cold-water fish, including anadromous fish. With reduced snowmelt, existing cold-water pools behind major foothill dams are likely to shrink. As a result, river water temperature could warm beyond a point that is tolerable for the salmon and steelhead that currently rely upon these rivers during the summer. Under this scenario, there is concern about how to maintain the existing, cold-water temperature standards in the upper Sacramento River.

Nutrient loading generally increases with runoff, particularly in human-dominated landscapes (Alexander et al. 1996). Delivery of constituents like phosphorus, pesticides, or acids in pulses can have adverse consequences for fishes. Increased numbers of water-quality excursions that exceed ecological thresholds will limit the effectiveness of policies designed for average conditions (Murdoch et al. 2000).

Peak flows occurring much earlier in the season (Leong and Wigmosta 1999, Hay et al. 2000) could result in washout of early life-history stages of autumn-spawning salmonids. Changes in sediment loading and channel morphology in an altered climate can impact processes regulating nutrient cycling and community composition (Ward et al. 1992).

Burkett and Kusler (2000) reviewed likely climate change impacts on wetlands. They concluded that expected changes in temperature and precipitation would alter wetland hydrology, biogeochemistry, plant species composition, and biomass accumulation. Because of fragmentation resulting from past human activities, wetland plants often cannot migrate in response to temperature and water-level changes and hence are vulnerable to complete elimination. Wetland plant response to increased CO₂ could also lead to shifts in community structure with impacts at higher trophic levels. Small changes in the balance between precipitation and evapotranspiration can alter groundwater level by a few centimeters, which can significantly reduce the size of wetlands and shift wetland types. Burkett and Kusler (2000) note that

there are no practical options for protecting wetlands as a whole from rising temperature and sea level and changes in precipitation. Some management measures could be applied to specific places to increase ecosystem resilience or to partially compensate for negative impacts, but there is often no explicit economic or institutional support for doing so. Among the options for mitigation are development setbacks for coastal and estuarine wetlands, linking fragmented ecosystems to provide plant and animal migration routes, using water-control structures to enhance ecosystem function, and explicit protection and allocation of water needed for ecosystem health. Some research has been done on these issues, but far more is needed, including modeling and experimental work on the interactions with food webs and hydrological regime (Power et al. 1995, Carpenter et al 2000).

Increased concentrations of greenhouse gases has been observed to both either increase and decrease plant growth, depending on species and the availability of other key growth conditions (Field et al. 1995). Availability of water at a critical time of the plant life will determine actual plant growth. Predicted drier summers might adversely affect drought sensitive plants. Further research has to be done in translating possible increase plant growth to increase in yield.

Water Demand

There are likely to be changes in water use, as well as in water supply. In general, plant ET increases with temperature. Higher carbon dioxide levels, however, reduce water consumption (at least in laboratory tests), and seem to increase yield (Korner 2000, but see Shaw et al. 2003). The higher water consumption with warmer temperatures will likely only be partially offset by the carbon dioxide-based reductions. Thus, the net result could be slightly higher agricultural water requirements. Assessing the potential impacts to agriculture is complicated for some of the annual crops because it may be possible to adjust the planting season to adapt.

The whole subject of potential crop ET and water requirements is an important area of investigation for university and agriculture extension service people. In view of further cuts in water availability to California agriculture, changes in ET would be of great importance. Further modeling and experimental work is needed.

3. Is Climate Change Already Affecting California's Water?

Temperature and Related Trends

The average surface temperature of the Earth has increased by around 0.6 degrees Celsius over the past century (NRC 2000). The fifteen warmest years this century have all occurred since 1980 and, the 1990s were the warmest decade of the entire millennium (Mann and Bradley 1999). Temperatures in the United States have also increased. Pronounced warming has occurred in winter and spring, with the largest increases in the period March-May over the western U.S. (Lettenmaier et al 1994, Dettinger et al. 1995, Vincent et al. 1999). Figures 6 and 7 show global and hemispheric temperature trends.

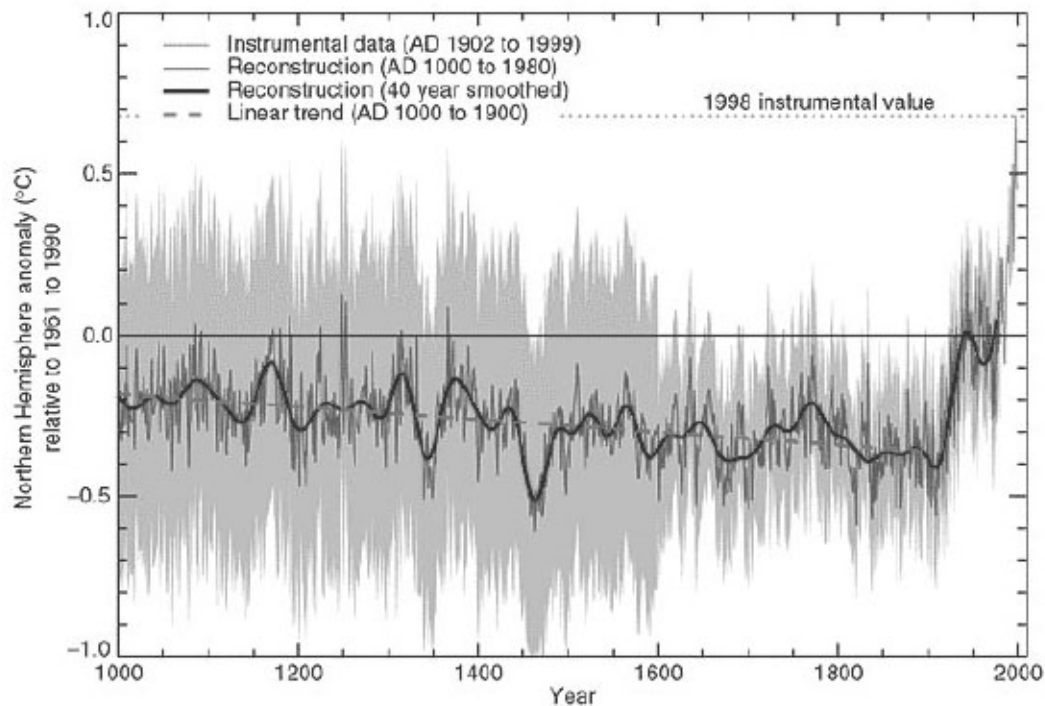


Figure 6: Global temperatures have been rising sharply in the northern hemisphere since the industrial revolution. This graph shows Northern Hemisphere temperature reconstruction from paleoclimate data (blue) and instrumental data (red) from AD 1000 to 1999, adapted from Mann et al. (1999). Smoother version of NH series (black), linear trend from AD 1000 to 1850 (purple-dashed) and two standard error limits (grey shaded) are shown.

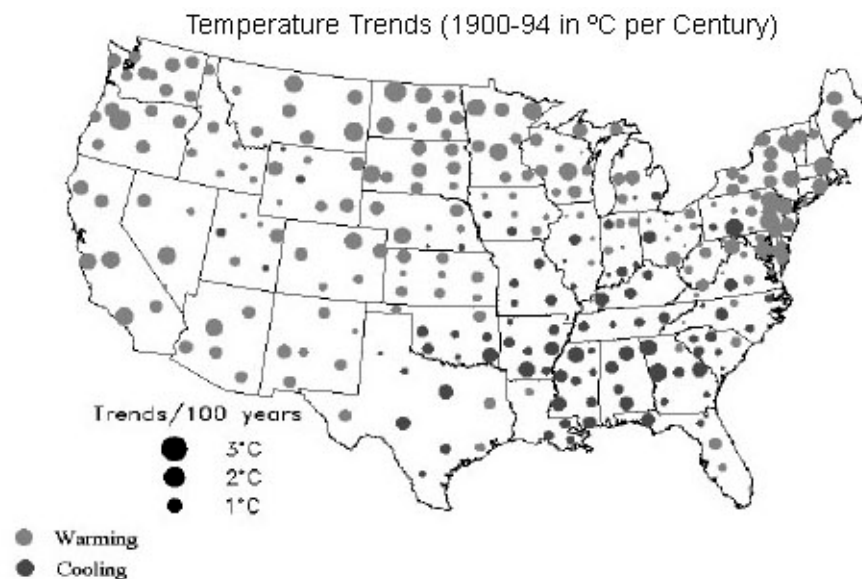


Figure 7: Temperature Trends in the Continental United States (1900 to 1994)

Precipitation Trends

Karl and Knight (1998), updated by Groisman et al. (2001) show an increase in precipitation in the continental United States, with most of the increase in the highest annual one-day precipitation event – a potentially worrisome trend in regions where flooding is a problem (Figure 8). By analyzing long-term precipitation trends in the United States, they determined that:

- Precipitation over the contiguous U.S. has increased by about 10 percent since 1910;
- The intensity of precipitation has only increased for very heavy and extreme precipitation days;
- Increases in total precipitation are strongly affected by increases in both the frequency and the intensity of heavy and extreme events, measured as the highest 1-day annual precipitation event;
- The probability of precipitation on any given day has increased;
- The proportion of total precipitation from heavy events has increased at the expense of moderate precipitation events.

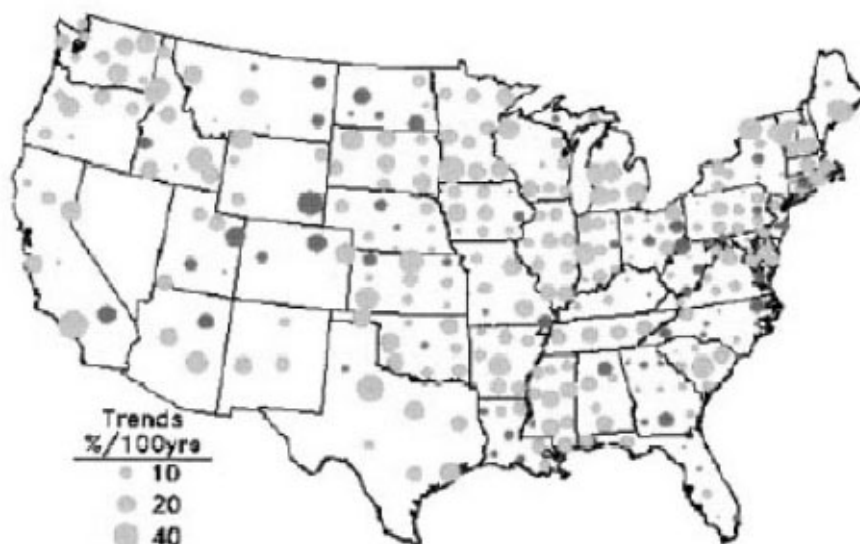


Figure 8. From Groisman et al. (2001). Linear trends in percent per 100 years of annual precipitation. Green dots indicate increase precipitation; brown dots indicate decreasing precipitation.

Runoff Trends

River runoff or discharge reflects multiple climatic factors, which makes it an important indicator of climatic variability and change. Discharge also integrates numerous human influences such as flow diversions for irrigation and municipal use, natural streamflow regulation by dams and reservoirs, and baseflow reduction by groundwater pumping. Detecting a climate signal in the midst of these complicating factors can be difficult (Changnon and Demissie 1996) and this is one of the most active areas for ongoing research.

Shortly after early modeling studies projected changes in the timing of runoff with increasing temperatures (Gleick 1986, 1987), DWR hydrologist Maurice Roos provided empirical evidence consistent with these projections (Roos 1987). In recent years, these changes in timing of streamflow have gained in statistical significance (shown in Figure 9).

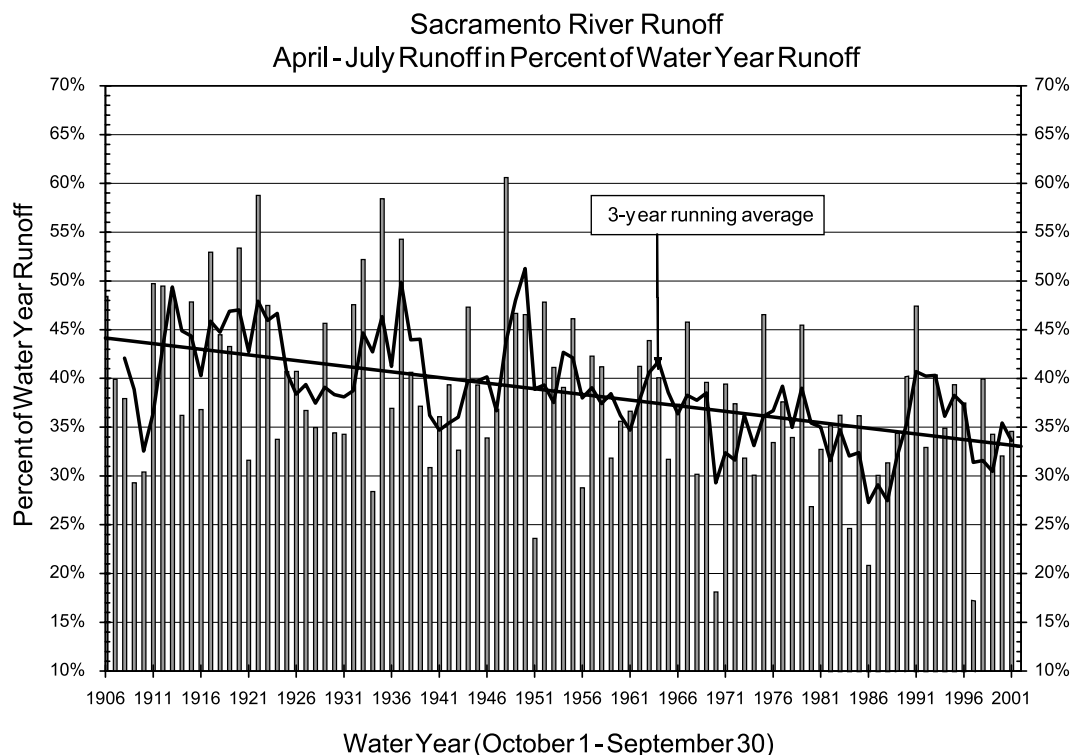


Figure 9. Historical trend in seasonal runoff for the Sacramento River. The decreasing percentage of April-July runoff indicates an earlier melting of the seasonal mountain snowpack.

Lins and Slack (1999) looked at historical trends in monthly mean flow across broad regions of the U.S., finding statistically significant increases in California. Lettenmaier et al. (1994) evaluated trends using monthly mean discharge and also found significant increases in western streamflow from 1948 through 1988. During 1948 through 1991, snowmelt-generated runoff came increasingly early in the water year in many basins in northern and central California. A declining fraction of the annual runoff was occurring during April to June in middle-elevation basins (as described above) and an increasing fraction was occurring earlier in the water year, particularly in March (Dettinger and Cayan 1995). Gleick and Chalecki (1999) observed this same basic pattern in an analysis of the Sacramento and San Joaquin Rivers over the entire twentieth century.

Groisman et al (2000) found little relation between increases in heavy precipitation and changes in high streamflow, similar to Lins and Slack (1999). More recently, however, Groisman et al (2001) have documented an increase in precipitation and especially heavy precipitation in the US as a whole, and related changes in peak streamflow. The changes were most notable in the eastern US because changes in snowcover in the west have complicated runoff studies. In the mountainous western US, snow cover has significantly retreated during the latter half of the 20th century, and there have been related shifts in seasonal discharges, but peak flows have not increased because of the changes in timing.

Snowmelt-runoff timing shifts, especially in middle-elevation mountainous river basins are important because of their sensitivity to changes in mean winter temperatures (Dettinger and Cayan 1995). However, as Dettinger and Cayan further note, the observed hydrologic shifts in these areas can involve more than simple relationships with air temperature alone.

Climate models and theoretical studies of snow dynamics have long projected that higher temperatures would lead to a decrease in the extent of snow cover in the Northern Hemisphere (see, for example, Dettinger and Cayan 1995, Cayan 1996). Recent field surveys corroborate these findings. Snow cover over the Northern Hemisphere land surface has been consistently below the 21-year average (1974 to 1994) since 1988 (Robinson et al. 1993, Groisman et al. 1994), with an annual mean decrease in snow cover of about 10 percent over North America.

Variability and Extreme Events

Extreme weather events are expected to be one of the most significant impacts of climate change. Phenomena such as the El Niño/Southern Oscillation, which is the strongest natural interannual climate fluctuation, have effects on the entire global climate system and the economies and societies of many regions and nations, including the U.S. The strong El Niños of 1982/83 and 1997/98, along with the more frequent occurrences of El Niños in the past few decades, have forced researchers to try to better understand how human-induced climate change may affect interannual climate variability (Trenberth and Hoar 1996, Timmermann et al. 1999). Analyses of flood risks are traditionally based on past data and on a fundamental assumption that peak floods are “random, independent, and identically distributed events.” This assumes that climatic trends or cycles are not affecting the distribution of flood flows and that the future climate will be similar to past climate. Current concern over natural variability, anthropogenic climate change, and possible impacts on hydrology, however, calls this assumption into question (NRC 1998).

4. Climate Change and Impacts on Managed Water-Resource Systems

There is a rapidly growing literature about how climate changes may affect U.S. water resources systems (see www.pacinst.org/resources for a searchable bibliography). Research has been conducted on a wide range of water-system characteristics, including reservoir operations, water quality, hydroelectric generation and others. At the same time, significant gaps remain.

The Central Valley Project and the State Water Project are each operated under strict guidelines, with constraints that have to be met prior to water being available for export. Flood control storage in reservoirs, water rights in upper Sacramento and San Joaquin, minimum flow requirements in the rivers and the Delta, dissolved oxygen concentration in the Stanislaus River, 800,000 ac-ft per year reserved for restoration of fish, wildlife and habitat restoration and salinity standards in the Delta are all considered in pumping operations. Even under existing supply and demand patterns, water requirements are barely met under dry and critical water years. Modifying existing constraints and optimizing the current operation of the system should be looked into, especially due to the possibility of a reduced supply of water at critical times due to climate change.

Precipitation, temperature, and carbon dioxide levels affect both the supply of, and demand for, renewable water resources. Agricultural, urban, industrial and environmental needs will each increase at certain

times of the year. For example, irrigation is particularly sensitive to climatic conditions during the growing season. Also, while indoor domestic water use is not very sensitive to temperature and precipitation, outdoor uses for gardens and parks are very climate dependent. And, higher water temperatures would reduce the efficiency of cooling systems and increase the demand for cooling water. Thus, climate will affect overall water use directly and indirectly.

Water Supply Infrastructure

A major challenge facing hydrologists and water managers is to evaluate how changes in system reliability resulting from climate changes may differ from those anticipated from natural variability and, in theory, already anticipated in original project designs. Both surface and groundwater supply systems are known to be sensitive to the kinds of changes in inflows and demands described earlier. Many regional studies have shown large changes in the reliability of water yields from reservoirs could result from small changes in inflows (Nemec and Schaake 1988, USEPA 1989, Lettenmaier and Sheer 1991, McMahon et al. 1989; Cole et al. 1991; Mimikou et al. 1991; Nash and Gleick 1991b, 1993). Lettenmaier and Sheer (1991), for example, noted the sensitivity of the California State Water Project to climate change under current operating rules. They concluded that changes in operating rules might improve the ability of the system to meet delivery requirements, but only at the expense of an increased risk of flooding. This kind of trade off is now being seen in a broader set of analyses.

Changes in runoff were the most important factors determining the climate sensitivity of system performance (Lettenmaier et al. 1999), even when they evaluated the direct effects of climate change on water demands. These sensitivities depended on the purposes for which water was needed and the priority given to those uses. Higher temperatures increased system use in many basins, but these increases tended to be modest, as were the effects of higher temperatures on system reliability.

Hydropower and Thermal Power Generation

California produces hydropower at a rate second only to the Pacific Northwest. The amount of hydropower production for a given facility is function of amount of water available, head over which the water falls, and time of operation. Changes in precipitation amount or pattern will have a direct impact on hydropower generation. If snowpack decreases, hydropower generation during these months would be reduced. However, wetter winters might enable additional hydropower generation during winter and spring if adequate flood control can be provided.

Variability in climate already causes variations in hydroelectric generation. During a recent multi-year drought in California, decreased hydropower generation led to increases in fossil-fuel combustion and higher costs to consumers. Between 1987 and 1991, these changes cost ratepayers more than \$3 billion and increased greenhouse gas emissions (Gleick and Nash 1991). Because of conflicts between flood-control functions and hydropower objectives, human-induced climate changes in California may require more water to be released from California reservoirs in spring to avoid flooding. This would result in a reduction in hydropower generation and the economic value of that generation. At the same time, production of power by fossil fuels would have to increase to meet the same energy demands in California at a cost of hundreds of millions of dollars and an increase in emissions of greenhouse gases (Hanemann and McCann 1993).

Climate changes that reduce overall water availability or change the timing of that availability have the potential to adversely affect the productivity of U.S. hydroelectric facilities. In contrast, reliable increases in average flows would increase hydropower production. More sophisticated studies such as that by Lettenmaier et al. (1999) are necessary for CA. Alternative sources of energy, combined with energy conservation, may be necessary means of adapting to decreased hydropower.

Agriculture

The strong links between water-resources availability and use and agricultural productivity deserve some comment here. In particular, relatively small changes in water availability could lead to relatively large impacts in the agricultural sector. Assessing the impacts of climate change on agriculture requires integrating a wide range of factors.

In the mid-1990s, approximately 75 percent of all water consumption occurred in California's agricultural sector. In California, the vast majority of agricultural production requires irrigation water from both surface and groundwater sources. Increases in water availability due to climate changes could help reduce the pressures faced by growers; conversely decreases in water availability are likely to affect growers more than other users for two reasons: urban and industrial users can pay more for water; and proportional reductions in water availability would lead to larger overall reductions to farmers. If irrigators holding senior water rights are allowed to sell or transfer those rights, some could actually benefit from decreases in water availability (Gleick and others 2000).

Brumbelow and Georgakakos (2000) assessed changes in irrigation demands and crop yields using physiologically based crop models, and reached several important conclusions for regional agricultural changes, though their results are dependent upon a single climate scenario and hence should be considered speculative. Durum wheat irrigation needs decreased significantly in California (82% decrease). Corn irrigation demands strongly decreased west of the 104th meridian (40% to 75% decrease) and were otherwise only slightly changed. In all regions, the length of the overall growing season increased. Economics of crop changes and quantitative water use figures are subjects for future research.

Extreme Events

Much of the analysis of climate and water impacts looks at how changes in various means will affect water and water systems, such as mean temperatures, average precipitation patterns, mean sea-level, and so on. While many factors of concern are affected by such average conditions, some of the most important impacts will result, not from changes in averages, but from changes in local extremes. Water managers and planners are especially interested in extreme events and how they may change with climate change. Unfortunately, this is one of the least-well understood categories of impacts and we urge more effort be devoted to studying it. Hydrological fluctuations impose two types of costs on society: the costs of building and managing infrastructure to provide more even and reliable flows and the economic and social costs of floods and droughts that occur in spite of these investments.

Ironically, some regions could be subjected to both increases in droughts and increases in floods if climate becomes more variable. Even without increases in variability, both problems may occur in the same region. In California, where winter precipitation falls largely as snow, higher temperatures will increase the ratio of rain to snow, shifting peak runoff toward the period of time when flood risk is

already highest. At the same time, summer and dry-season runoff will decrease because of a decline in snowpack and accelerated spring melting.

Floods

Flooding is the nation's most costly and destructive natural disaster. A change in flood risks is therefore one of the potential effects of climate change with the greatest implications for human well-being. Few studies have looked explicitly at the implications of climate change for flood frequency, in large part because of the difficulty of getting detailed regional precipitation information from climate models and because of the substantial influence of both human settlement patterns and water-management choices on overall flood risk. Floodplain development places more people and property at risk and it reduces a basin's capacity to naturally absorb flood flows.

Future flood damages will depend on many factors. Among the most important are the rate and style of development in the floodplains, the level and type of flood protection, and the nature of climate-induced changes in hydrological conditions, sea levels, and storm surges. As noted earlier, regional and local changes in hydrological conditions attributable to a greenhouse warming are uncertain but research to date suggests that there is a risk of increased flooding in California. In any case, flooding depends not only on average precipitation but on the timing and intensity of precipitation – two characteristics not well modeled at present. •Kiparsky and Gleick 2003 Page 29

Droughts

Water managers must also be concerned about the risks of droughts. Droughts vary in their spatial and temporal dimensions and are highly dependent on local management conditions and the perceptions of local water users. No single definition of drought applies in all circumstances; thus determining changes in drought frequency or intensity that might be expected to result from climate changes is complicated. Most past studies have focused on evaluating changes in low-flow conditions and probabilities.

Quantifying the socioeconomic impacts of a drought is difficult, and comprehensive damage estimates are rarely available. Agriculture, the economic sector most susceptible to water shortages, is likely to suffer reduced crop production, soil losses due to dust storms, and higher water costs during a drought. But non-climatic factors can play an important role in limiting, or worsening, the impacts of climate. Agricultural losses during California's six-year drought from 1987-1992 were reduced by temporarily fallowing some land, pumping more groundwater, concentrating water supplies on the most productive soils and higher value crops, and purchasing water in spot markets to prevent the loss of tree crops. Direct economic losses to California's irrigated agriculture in 1991 were estimated at only \$250 million, less than 2 percent of the state's total agricultural revenues (Nash 1993, U.S. Army Corps of Engineers 1994).

A prolonged drought affects virtually all sectors of the economy. Urban users in California paid more for water and were subject to both voluntary and mandatory conservation programs. Landscaping and gardening investments and jobs were lost. Electricity costs, as described above, rose more than \$3 billion because of reduced hydropower production. Recreation was adversely impacted. Visits to California state parks declined by 20 percent between 1987 to 1991, and water-based activities such as skiing and reservoir fishing declined (Gleick and Nash 1991). During this drought, the state's environmental resources may have suffered the most severe impacts. Most major fisheries suffered sharp declines and many trees were weakened or killed by the lack of precipitation, increasing the subsequent

risk of forest fires (Nash 1993, Brumbaugh et al. 1994). Many of these ecosystem impacts are never monetized or quantified.

5. Coping and Adaptation: Policy Directions

Review of Policy Recommendations from Peer-Reviewed Sources

For over a decade, scientists have been producing formal, peer-reviewed recommendations for integrating their work into policy. We synthesize their suggestions for coping and adaptation from several key reports. Each recommendation is followed by one or more references indicating which reports included it. While only the California Energy Commission report (1991) is wholly specific to California, it should be noted that most focus on the Western United States, including California, because in general impacts of climate change on water resources are expected to be greater in areas which are already water-stressed. The following reports are used in this synthesis:

- (Waggoner 1990) – The American Association for the Advancement of Science published this volume detailing the setting, impacts, and responses for U.S. water resources. It was the most in-depth, interdisciplinary, and scientifically sophisticated report until the National Assessment (Gleick and others 2000).
- (California Energy Commission 1991) – The first report by a California State agency was mandated by AB4420 in 1988. The CEC report is specific to California, and produced under the auspices of a California Agency. It should be noted that its recommendations were based on the assumption that snowmelt timing will be the primary hydrologic variable altered by climate change, and precipitation was held constant in its scenarios.

In our interviews, California water policymakers cited it repeatedly as an influential early document.

- (American Water Works Association 1997) – The Public Advisory Forum of the American Water Works Association issued a succinct set of recommendations to water managers. As the largest U.S. professional water utilities and providers' organization, its peer-reviewed document should carry weight with water managers.
- (Gleick and others 2000) – The report of the Water Sector of the National Assessment on the Potential Consequences of Climate Variability and Change for the United States provides a regional and national overview of the impacts of climate change on water resources.
- (Wilkinson and others 2002) – The draft report of the California Regional Assessment Group of the National Assessment provides an overview of impacts for the State's ecosystems, economy, society, human health, and other areas. It includes a major chapter on water resources. In its section on recommendations for adaptation, it quotes in full the Water Sector (Gleick and others 2000) and the AWWA reports (American Water Works Association 1997). In addition, it offers other recommendations, which are cited in this summary.

These reports were all peer-reviewed, except the CEC report, which is included because of its historical influence and the degree of its specificity to California. A general theme in the recommendations is the adoption of “no-regrets” strategies, which are defined by the IPCC as policies that would have net social benefits whether or not there is anthropogenic climate change (McCarthy et al. 2001).

In the context of broad scientific consensus that global climate change is real and expected with a very high degree of confidence, these recommendations also implicitly or explicitly acknowledge that specific

regional effects are not yet predictable with high certainty. This point was emphasized in the recommendations of the AAAS report (Waggoner 1990).

It is also notable that none of the reports contradict each other on any specific recommended measure. This consistency follows from the general scientific consensus on global climate change, but also from the generally conservative nature of the suggestions. Even the California Energy Commission report (1991), with its less-sophisticated scientific basis, produced recommendations that are consistent with those of later efforts. Some of the recommendations have been acted on, and some responses are currently being devised.

We divided the list below into four categories: Current No-Regrets Actions, Communication and Collaboration, Research Needs, and Information Gathering.

Current No-Regrets Actions

- Governments and agencies should reevaluate legal, technical, and economic procedures for managing water resources in the light of the climate changes that are highly likely (Waggoner 1990; American Water Works Association 1997; Gleick and others 2000; Wilkinson and others 2002).
- Governments should encourage flexible institutions for water allocation including water markets (Waggoner 1990).
- Planning should occur over appropriate regions which may or may not correspond to current boundaries (Waggoner 1990). This would elevate the importance of hydrologic boundaries over political boundaries.
- Increased funding is necessary for interdisciplinary research necessary to address the broad-based impacts and effects of climate change (Waggoner 1990).
- Flexible decisions should be encouraged, particularly in the design and construction of new projects (Waggoner 1990; Gleick and others 2000; Wilkinson and others 2002). Kiparsky and Gleick 2003
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- Opportunities for water conservation, demand management, and efficiency should be explored and encouraged (Waggoner 1990; California Energy Commission 1991; Gleick and others 2000; Wilkinson and others 2002).
- Private enterprises should decrease vulnerabilities to the hydrologic effects of climate change through water transfers or construction of new infrastructure (Waggoner 1990).
- The State should improve both weather and flood forecasting (California Energy Commission 1991).
- The State should assess Delta levees' strength with respect to increasing sea level rise (California Energy Commission 1991).
- Water managers should carefully consider increased storage in new surface or underground storage facilities (California Energy Commission 1991; Gleick and others 2000). The California Energy Commission (1991) gave the most specific recommendation, at four million acre feet, plus storage for maintenance of Delta salinity levels. This estimate, however, should be taken in the context of the relative generality of its science.
- Existing dams should have temperature controls added for fish species that require cold water downstream (California Energy Commission 1991).

- New supply should come from both traditional and alternative places, such as wastewater reclamation and reuse, water marketing and transfers, and possibly desalination (Gleick and others 2000).
- Prices and markets should be adjusted to balance supply and demand (Gleick and others 2000).
- Water laws should be updated and improved water laws, including review of the legal allocation of water rights (American Water Works Association 1997; Gleick and others 2000).
- Managers should plan and invest for multiple benefits (e.g. Water supply, energy, wastewater, and environmental benefits result from water use efficiency increases) (Wilkinson and others 2002).
- Site-dependant application of climate change science to stormwater management strategies should be used, including approaches like increasing permeable surfaces in urban areas (Wilkinson and others 2002).

Communication and Collaboration

- Water organizations should communicate regularly with scientists, with the dual goals of communicating scientific advances to managers, and communicating what knowledge is necessary from scientists for effective management (Waggoner 1990; American Water Works Association 1997; Gleick and others 2000).
- “Those reporting about climate change bear a special responsibility for accuracy, conveying the real complexities and uncertainties, and not oversimplifying. Scientists must make extra effort to explain clearly in conservative and understandable terms.” (Waggoner 1990).
- Timely flows of information between scientific community, public, and water management should be facilitated (American Water Works Association 1997; Gleick and others 2000).¹

Research Needs

There is no shortage of research needs, several of which are listed below. The PIER project has developed a research agenda, short-term (1 to 3 years), mid-term (3 to 10 years), and long-term (10 to 20 years), to attempt to answer some of the most important questions facing California policymakers and scientists. Funding is not available for all of the necessary work. Roos (2003) describes this “roadmap” at www.energy.ca.gov/reports/2003-04-16_500-03-025FA-II.PDF.

This roadmap has been approved by the California Department of Water Resources to help it develop future research efforts.

Other research needs include:

- Climate change scientists should focus on the timeframes and spatial scales relevant to water managers, who are concerned with watershed-level predication and decadal time scales (Waggoner 1990).
- Improve GCMs to more accurately represent hydrologic impacts, water resource availability, overall hydrologic impacts, and regional impacts (Waggoner 1990; Gleick and others 2000).
- Improve downscaling of GCMs ² (Gleick and others 2000).
- Planners should reassess water transfer plans for the Sacramento-San Joaquin Delta, particularly in light of predicted sea-level rise (California Energy Commission 1991).
- Changing land use patterns should be examined as a coping mechanism (Gleick and others 2000).

- Scientists and engineers should reexamine engineering designs, operating rules, contingency plans, and water allocation policies under a wider range of climate scenarios³ (American Water Works Association 1997; Gleick and others 2000).
- Economists should investigate economic effects of climate change and of adaptations to climate change (Gleick and others 2000).
- Hydrologists should research effects on groundwater quality, recharge and flow dynamics has been lacking (Gleick and others 2000).
- All sectors should look into mitigation through decrease in fossil fuel use (California Energy Commission 1991; American Water Works Association 1997).

Information Gathering

- The state should improve hydrologic monitoring, including improving data on storm frequency (California Energy Commission 1991; Gleick and others 2000).
- Water quality monitoring should be increased (California Energy Commission 1991).
- The State should reevaluate risks to flood zones at intervals of 20-30 years (California Energy Commission 1991).
- Information on the relative costs and benefits of non-structural managements options, like demand management or decreased floodplain development should be produced (Gleick and others 2000).
- Agencies should explore the vulnerability of both structural and nonstructural water systems (American Water Works Association 1997).
- Economic and market tools should be explored, but Wilkinson and others (2002) caution that this should not be equated with privatization.

In the context of these recommendations for types of action, the following more specific items are available within several major topical categories. Among the new tools water agencies and managers are exploring are (1) incentives for conserving and protecting supplies, (2) opportunities for transferring water among competing uses in response to changing supply and demand conditions, (3) economic changes in how water is managed within and among basins, (4) evaluating how “re-operating” existing infrastructure can help address possible changes, and (5) new technology to reduce the intensity of water use to meet specific goals (Gleick and others 2000).

6. Coping and Adaptation: Specific Policy Actions

The lessons from existing efforts need to be evaluated in order to understand how they might mitigate (or worsen) the impacts of climate changes. During the 20th century dams, reservoirs, and other water infrastructure were designed with a focus on extreme events such as the critical drought periods or the probable maximum flood. This approach provided a cushion to deal with uncertainties such as climate variability (Matalas and Fiering 1977). In recent years, however, the high costs and environmental concerns that now make it difficult to get a new project approved also make it likely that the projects that are undertaken will have less redundancy built into their water supply and control facilities than the projects built earlier (Frederick 1991).

Managing water resources with climate change could prove different than managing for historical climate variability because 1) climate changes could produce hydrologic conditions and extremes of a different nature than current systems were designed to manage; 2), it may produce similar kinds of variability but

outside of the range for which current infrastructure was designed; 3), it assumes that sufficient time and information will be available before the onset of large or irreversible climate impacts to permit managers to respond appropriately; 4) it assumes that no special efforts or plans are required to protect against surprises or uncertainties (Gleick and others 2000). This chapter of Bulletin 160-2003 represents an important acknowledgement by a major state agency of the realities and necessities inherent to a changing climate.

Water Planning and Management

Decisions about long-term water planning depend on climatic conditions and what humans do to respond and adapt to those conditions. In the past, these decisions relied on the assumption that future climatic conditions would have the same characteristics and variability as past conditions. Dams are sized and built using available information on existing flows in rivers and the size and frequency of expected floods and droughts. Reservoirs are operated for multiple purposes using the past hydrologic record to guide decisions. Irrigation systems are designed using historical information on temperature, water availability, and soil water requirements.

This reliance on the past record now may lead us to make incorrect – and potentially dangerous or expensive – decisions. Given that risk, one of the most important coping strategies must be to try to understand what the consequences of climate change will be for water resources and to begin planning for those changes. Emphasis on planning and demand management rather than construction of new facilities marks an important change in traditional water-management approaches, which in the past have relied on the construction of large and expensive infrastructure.

- O’Conner et al. (1999) examined the sensitivity and vulnerability of community water systems to climate change by surveying 506 managers. Water-system managers do not dismiss the issue of climate change, but they have been reluctant to consider it in their planning horizons until they perceive a greater degree of scientific certainty about regional impacts. Interestingly, most managers admit that they expect disruptions in daily operations caused by changes in climate variability. Experienced and full-time water managers were more likely to consider future climate scenarios in planning than inexperienced or part-time managers. O’Conner et al (1999) offered some conclusions and discussion of policy implications of their survey: Moving away from exclusive reliance on surface water by integrating surface and groundwater management reduced vulnerability to climate fluctuations;
- Continued efforts to improve research and to communicate the risk of climate changes to water managers, especially at the local level, will be useful; and
- Local governments should consider creating more full-time water manager positions to attract top professionals capable of considering long-term issues and concerns in planning.

Sea Level Concerns

Five hundred and twenty miles of levees that protect the Delta Islands are non-project (outside the federal flood control project) levees that are currently built to HMP (Hazard Mitigation Plan) standards. Local districts responsible for maintaining these levees are challenged by poor foundations and regulations to protect levee wild life habitat. An estimated expenditure of from \$613 million to \$1.28 billion would bring the levees up to Public Law 84-99 standard (16 ft wide and 1.5 ft free board above a 100-year flood) (personal communication, Department of Water Resources, 2003).

To increase these non-project levees by one additional foot (to accommodate sea level rise) would increase the cost by about \$300 million. There are currently 220 miles of project levees in the Delta region, which are mostly up to PL 84-99 standards. It will cost over \$130 million to accommodate an increase of a foot in this levee system. An additional increase in the water level due to sea level rise would necessitate not only an increase in the levee height but also strengthening the levees.

Modifying Operation of Existing Systems

There are two critical issues associated with using existing facilities to address future climate change: can they handle the kinds of changes that will occur; and at what economic and ecological cost? There have been few detailed analysis of either of these questions, in part because of the large remaining uncertainties about how the climate may actually change. Also, the principle of local public participation is increasingly being implemented. Involving the public in water management decisions has taken steps forward in California through the CALFED process (cite Environment paper) and through the public advisory committee role in the production of this document.

Regardless, without precise information on the characteristics of future climate, the best that water managers can hope to do may be to explore the sensitivity of their system to a wider-range of conditions than currently experienced and to develop methods or technologies that can improve operational water management.

The work of Lettenmaier et al. (1999) and Georgakakos and Yao (2000a,b) reinforce the conclusion that effective operation of complex systems can reduce impacts of climate change, but only if implemented in a timely and dynamic manner. Lettenmaier et al. (1999) addressed this question of response to climate change for a series of water systems around the United States. They noted that reservoir systems buffer modest hydrologic changes through operational adaptations. As a result, the effects of climate change on the systems they studied tend to be smaller than the underlying changes in hydrologic variables. They concluded that significant changes in design or scale of water management systems might not be warranted to accommodate climate changes alone, although this obviously depends on the ultimate size of the changes. They urged a concerted effort to adjust current operating rules or demand patterns to better balance the existing allocated purposes of reservoirs, which requires planning and participation by water managers.

Other steps should include determining quantitative impacts from climate change on water supply and flood control including a systematic review and evaluation of all major multi-purpose reservoirs for water supply and flood control and their ability to adapt under current operating rules. Also, evaluation of alternative options for water management including evaluation of measures to improve water supply and quality, reduce demands throughout the State, maintain and restore ecosystems, re-operate reservoirs, and adapt to sea level rise in the Delta. The work will emphasize increased flexibility in both physical systems and institutional mechanisms in order to permit a greater range of response. Supply and quality measures will be particularly important in regions dependent on imported supplies.

Due to the many uncertainties in predicting peak flows under climate change scenarios, a closer look at the design practices of hydraulic infrastructure should be considered. Related to flood risk are the rainfall depth-duration-frequency data widely used for designing local storm water control and drainage facilities.

It has been suggested that these statistics be updated frequently, at least every 20 years or so. In this way, climate changes will be gradually incorporated into the record and in the rainfall statistics.

New Supply Options

Traditional water-supply options, such as dams, reservoirs, and aqueducts may still have an important role to play in meeting water needs in parts of the United States. Because new infrastructure often has a long lifetime, it is vital that the issue of climate change be factored into decisions about design and operation.

While new supply options can be expensive and controversial traditional, water-supply options such as dams, reservoirs and aqueducts may still have an important role to play in meeting water needs of California. At present the Department of Water Resources in collaboration with United States Bureau of Reclamation (USBR), Contra Costa Water district (CCWD) and local agencies are looking into enlarging instream storages in Shasta and Millerton reservoirs, off stream storage options such as Red bank project, Colusa Reservoirs and Sites reservoirs, Enlarging Los Vaqueros reservoir and flooding four Delta islands namely Bacon, Web, Bouldin and Holland. These projects will increase supply reliability, improve water quality and improve some environmental issues such as providing wild life habitats and cooler water for salmon migration. Because new infrastructure often has a long lifetime, it is vital that the issue of climate change be factored into decisions about designs and operations.

Aside from new water-supply infrastructure, options to be considered include wastewater reclamation and reuse, water marketing and transfers, and even limited desalination where less costly alternatives are not available and where water prices are high. None of these alternatives, however, are likely to alter the trend toward higher water costs. They are either expensive relative to traditional water costs or their potential contributions to supplies are too limited to make a significant impact on long-term supplies. Ultimately, the relative costs, environmental impacts, and social and institutional factors will determine the appropriate response to greenhouse-gas induced climate changes.

Major (1998) notes that incremental construction can allow for adaptation but adds that planners must choose robust designs to permit satisfactory operation under a wider range of conditions than traditionally considered. Designing for extreme conditions, rather than simply maximizing the expected value of net benefits, should be considered. He also suggests postponement of irreversible or costly decisions.

Demand Management, Conservation, and Efficiency

Demand management, especially in face of population increase is critical to mitigate loss of water supply. More water efficient methods in agricultural, industrial and urban water have been effective in the past in this capacity (Owens-Viani et al. 1999), and should be further developed and implemented.

As the economic and environmental costs of new water-supply options have risen, so has interest in exploring ways of improving the efficiency of both allocation and use of water resources. Improvements in the efficiency of end uses and sophisticated management of water demands are increasingly being considered as major tools for meeting future water needs, particularly in water-scarce regions where extensive infrastructure already exists (Vickers 1991, Postel 1997, Gleick 1998a, Dziegielewski 1999, Vickers 1999). Evidence is accumulating that such improvements can be made more quickly and more

economically, with fewer environmental and ecological impacts, than further investments in new supplies (Gleick et al. 1995, Owens-Viani et al. 1999).

The largest single user of water is the agricultural sector and in some places a substantial fraction of this water is lost as it moves through leaky pipes and unlined aqueducts, as it is distributed to farmers, and as it is applied to grow crops. In water-short areas, new techniques and new technologies are already changing the face of irrigation. Identifying technical and institutional ways of improving the efficiency of these systems in a cost-effective manner will go a long way toward increasing agricultural production without having to develop new supplies of water (Gleick 1998a).

In an assessment of urban water use, Boland (1997, 1998) shows that water conservation measures such as education, industrial and commercial reuse, modern plumbing standards, and pricing policies can be extremely effective at mitigating the effects of climate change on regional water supplies. A number of water-system studies have begun to look at the effectiveness of reducing system demands for reducing the overall stresses on water supplies, both with and without climate changes. Wood et al. (1997) and Lettenmaier et al. (1999) noted that long-term demand growth estimates had a greater impact on system performance than climate changes in circumstances when long-term withdrawals are projected to grow substantially. Actions to reduce demands or to moderate the rate of increase in demand growth can therefore play a major role in reducing the impacts of climate changes. Far more work is needed to evaluate the relative costs and benefits of demand management and water-use efficiency options in the context of a changing climate.

Economics, Pricing, and Markets

Prices and markets are also increasingly important tools for balancing supply and demand for water and hence for coping with climate-induced changes. Economists and others are beginning to advocate an end to the treatment of water as a free good. This can be accomplished in many different ways. Because new construction and new concrete projects are increasingly expensive, environmentally damaging, and socially controversial, new tools such as the reduction or elimination of subsidies, sophisticated pricing mechanisms, and smart markets provide incentives to use less water, produce more with existing resources, and reallocate water among different users. Water marketing is viewed by many as offering great potential to increase the efficiency of both water use and allocation (NRC 1992, Western Water Policy Review Advisory Commission 1998). As conditions change, markets can help resources move from lower- to higher-value uses.

Water transfers in itself do not create new water, but simply reallocate water within a region or between regions. This process enables a better distribution of water throughout the State from areas of surplus to areas in need. In a guide to water transfer, the California State Water Resources Control Board stipulates that a person who transfers water should hold the rights to it and should not injure another water right holder or unreasonably effect instream beneficial uses. For efficient water marketing and smooth transferring of water the users should have a clear idea about the transfer costs.

Water banks acts as storage locations where excess water is held until a withdrawal is necessary. The storage location could be either a surface reservoir or a groundwater aquifer. Water banks enhance the versatility of water transfers and marketing, though many questions about equity, pricing, and operations remain to be answered.

The characteristics of water resources and the institutions established to control them have inhibited large-scale water marketing to date. Water remains underpriced and market transfers are constrained by institutional and legal issues. Efficient markets require that buyers and sellers bear the full costs and benefits of transfers. However, when water is transferred, third parties are likely to be affected. Where such externalities are ignored, the market transfers not only water, but also other benefits that water provides from a non-consenting third party to the parties to the transfer. A challenge for developing more effective water markets is to develop institutions that can expeditiously and efficiently take third-party impacts into account (Loh and Gomez 1996, Gomez and Steding 1998, Dellapenna 1999). As a result, despite their potential advantages, prices and markets have been slow to develop as tools for adapting to changing supply and demand conditions.

California's emergency Drought Water Banks in the early 1990s helped mitigate the impacts of a prolonged drought by facilitating water transfers among willing buyers and sellers. Dellapenna (1999) and others have noted, however, that the California Water Bank was not a true market, but rather a state-managed reallocation effort that moved water from small users to large users at a price set by the state, not a functioning market. More recent efforts to develop functioning markets on smaller scale have had some success (<http://rubicon.water.ca.gov/b16098/v2txt/ch6e.html>).

Temporary transfers may be particularly useful for adapting to short-term changes such as climate variability. They are less effective in dealing with long-term imbalances that might result from changing demographic and economic factors, social preferences, or climate. At some point, the historical allocation of water becomes sufficiently out of balance to warrant a permanent transfer of water rights.

State Water Law

Few analyses have tried to evaluate how climate change impacts may affect, and be affected by, water laws and regulatory structures. Water in its many different forms has been managed in different ways at different times, and in different places around the country, leading to complex and sometimes conflicting water laws. At the federal level, laws such as the Clean Water Act and the Safe Drinking Water Act have played a major role in how water is used, allocated, and treated. Yet these national tools, not to mention the many regional and local laws affecting water, were all designed without considering the possibilities of climate changes (Trelease 1977). Even without such changes, efforts are needed to update and improve legal tools for managing and allocating water resources. Tarlock (1991) evaluated how western water laws may begin to conflict as climate change affects water availability and reliability. Dellapenna (1999) argues that the current fragmented approach is obsolete and that integrated water management at the basin level is required, both with and without climate changes. He further argues, however, that climate changes are likely to exacerbate the problems that already exist under inefficient management.

Hydrologic and Environmental Monitoring

Better data on hydrology and land use are critical to California's successful adaptation to expected climate change. Changes in hydrology are among the most certain of climate change impacts and good hydro-meteorological data are the starting point for evaluating the capabilities of the current water supply and flood protection systems to continue to serve the people of California. Hydrological data are used in the design and operation of water supply systems and flood control works, the provision of environmental

needs, and in design of other infrastructure. Several State agencies have ongoing climate, water, and land use/land cover monitoring programs. But there are important gaps, particularly in areas where greater changes are anticipated. At a minimum, data must be collected in several important categories, including:

- Enhance measurements of precipitation and related climate data, streamflow, snowpack, ocean and Delta water levels.
- A water quality sampling network designed to look at changes expected from climate change.
- More systematic sea-level measurements in the San Francisco Bay and Delta region, and elsewhere along California's coast.
- Enhanced land use and cover monitoring within the State.

Finally, it is important to continue to collect, maintain, and evaluate records from existing California stations, incorporating data from recent years. Efforts should be made to prevent cuts in monitoring and data collection due to budget constraints.

Notes:

¹ Several recent conferences illustrate that this is currently happening. For example, at a recent CALFED meeting detailing modeling projects, several local stakeholder groups were represented along with larger environmental groups and many branches of government.

² This is one area that continues to see significant advances (eg. Knowles and Cayan 2002; Snyder et al. 2002). Interestingly, Knowles and Cayan (2002) acknowledge water managers at DWR for providing motivation for their work.

³ See (cite Georgakakos...)

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Accounting for Climate Change

By M. Roos

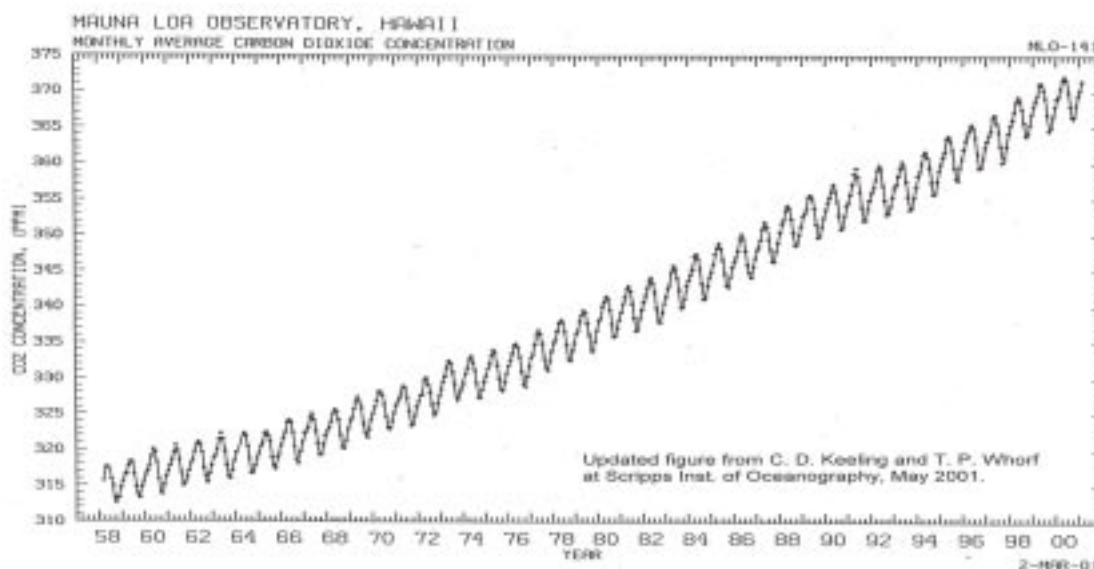
In recent years, evidence that global climate will have significant effects on water resources in California has continued to accumulate. Climate change can affect the amount, timing, and form of precipitation, whether rain or snow, that California receives, as well as the sea level of the Pacific Ocean. Moreover, changes in weather, especially temperature, and atmospheric composition can affect water use and consumption. Changes in climate have occurred during the 20th century, with noticeable warming in the last two decades.

Most scientists feel that changes during the last several decades are likely mostly due to human activities, but natural causes and variability cannot be ruled out as a significant component. Likewise, projections of amount of warming and other climate changes during the 21st century are wide ranging, depending on assumptions and models.

A major cause of expected climate change is the increasing amounts of greenhouse gases, such as carbon dioxide, in the atmosphere as a result of man's activities. These gases, as well as water vapor, allow solar radiation to pass inward through the atmosphere, but trap the longer wave infrared radiation reflected back from the earth's surface. Greenhouse gases are accumulating in the atmosphere; the following chart shows the gradual build up in carbon dioxide at Mauna Loa in Hawaii, as measured by Scripps Institution of Oceanography scientists. The annual cycle is caused by northern hemisphere vegetation uptake during the growing season. Other significant greenhouse gases are methane, nitrous oxide, halocarbons (like freon and its replacements), and, of course, water vapor itself. Cloud cover is an important element in the global radiation balance.

Whatever the causes, the prospects of significant changes warrant examination of how the State's water infrastructure and natural systems can accommodate or adapt to climate changes and whether more needs to be done to detect, evaluate and respond to water resource system effects. Many uncertainties remain, primarily on the degree of change to be expected. Responsible planning requires that the California water planning community work with climate scientists and others to reduce these uncertainties and to begin to prepare for those impacts that are well understood, already appearing as trends, or likely to appear. In this section we review possible impacts and address some of the responses appropriate for water planners and managers.

Figure 1.
Atmospheric Carbon Dioxide Concentration as measured at Mauna Loa, Hawaii



By and large, reservoirs and water delivery systems and operating rules have been developed from historical hydrology on the assumption that the past is a good guide to the future. With global warming, that assumption may not be valid.

Significant changes in climate are projected for the latter part of this century due to global warming. These potential changes are expected to affect many of our water resources systems. Some of the more important changes would arise from temperature increases, which would raise temperate zone snow elevations and change the pattern of runoff from mountain watersheds, thereby affecting reservoir operation. Other consequences include sea level rise, which could adversely affect the Sacramento San Joaquin River Delta, a major source of water supply for the State; possibly more extreme precipitation and flood events; changes in water consumption by crops and wildlands; and water temperature problems for anadromous fish.

The California Water Plan first briefly addressed climate change a decade ago in a sidebar in Bulletin 160-93 when there was less consensus that global warming was beginning. Prior to that, the California Energy Commission had produced an extensive report in 1991, in response to 1988 legislation, which had significant discussion on reduced snowpack and changing runoff patterns, sea level rise, and water temperatures. This was the first major report by a State agency on the subject.

Climate Projections

The most well known climate change projections by year 2100, the end of the century, due to the increase in greenhouse gases have been developed by the Intergovernmental Panel on Climate Change. The IPCC was jointly established in 1988 by the World Meteorological Organization and the United Nations Environment Programme to study climate change. The IPCC has issued several reports since 1990 outlining possible global warming and other potential effects of climate change as a result of increased greenhouse gases originating from human activities.

A good assessment of the state of research on the potential consequences of climate change on water resources in the United States, including what is known and what is not known, is the report of the National Water Assessment Group for the U.S. Global Change Research Program (Gleick and Adams, 2000).

The most recent IPCC Working Group I Summary Report, in its third assessment (IPCC, 2001), projects a 1990 to 2100 average surface temperature increase of around 3 degrees C, with a range of 1.4 to 5.8 degrees (2.5 to 10.4 degrees F). The increase in global temperature during the 20th century was estimated to be about 0.6 degrees C (1.0 degree F), much of which occurred by 1940, and a recent significant increase after 1980 which is believed to be primarily of human origin. Because of warmer temperatures, some increase in global evaporation and therefore more precipitation is projected for the 21st century, more likely at higher latitudes north of California.

The chart shows temperature trends for three groups of stations in California during the 20th century. What is notable is the urban heat island influence, wherein the counties with large populations show more warming than rural counties. Although not directly related to greenhouse gas increases, the local urban warming does matter to local residents because it affects their lives and local environment.

Sea level (IPCC, 2001) is projected to rise around 0.5 meter (1.6 feet) by 2100, with a range of 0.1 to 0.9 meters (0.3 to 2.9 feet). The rate during the 20th century appears to have been around 0.2 meters (0.7 feet) with a range of 0.1 to 0.25 meters (0.3 to 0.8 feet). The 0.2-meter figure is consistent with the historical trend at the Golden Gate tide station, although it is possible that tectonic movement, or settlement, has influenced the stages there.

Figure 2
Long term average temperatures at different locations in California (J. D. Goodridge)

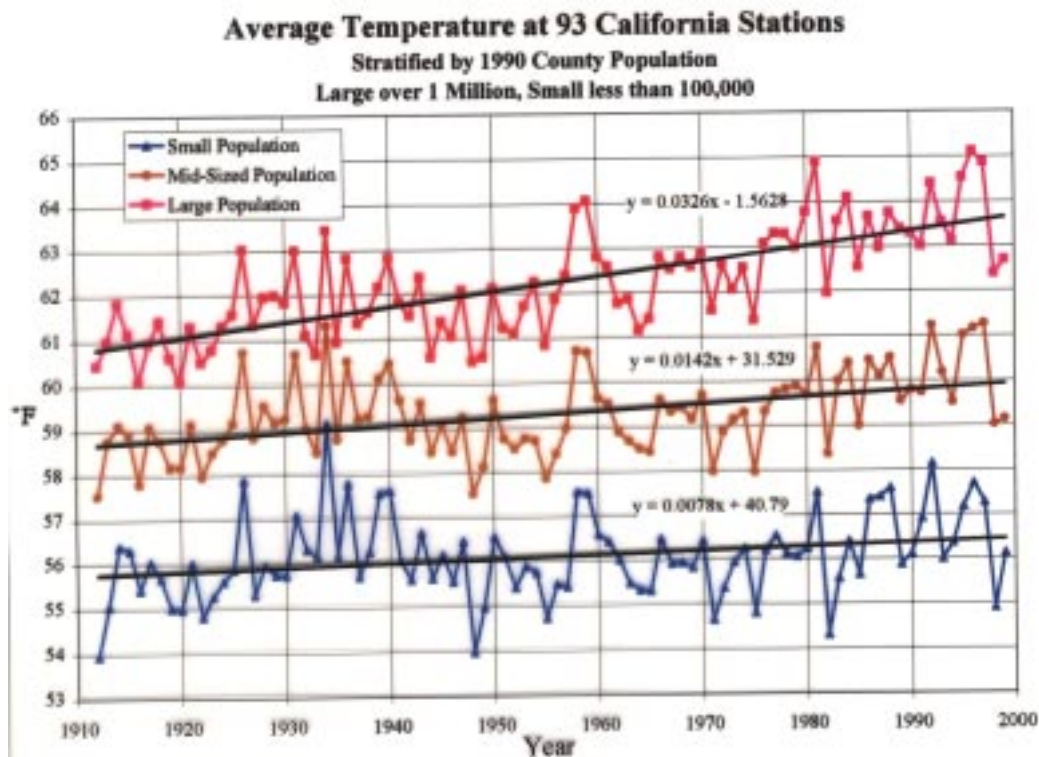
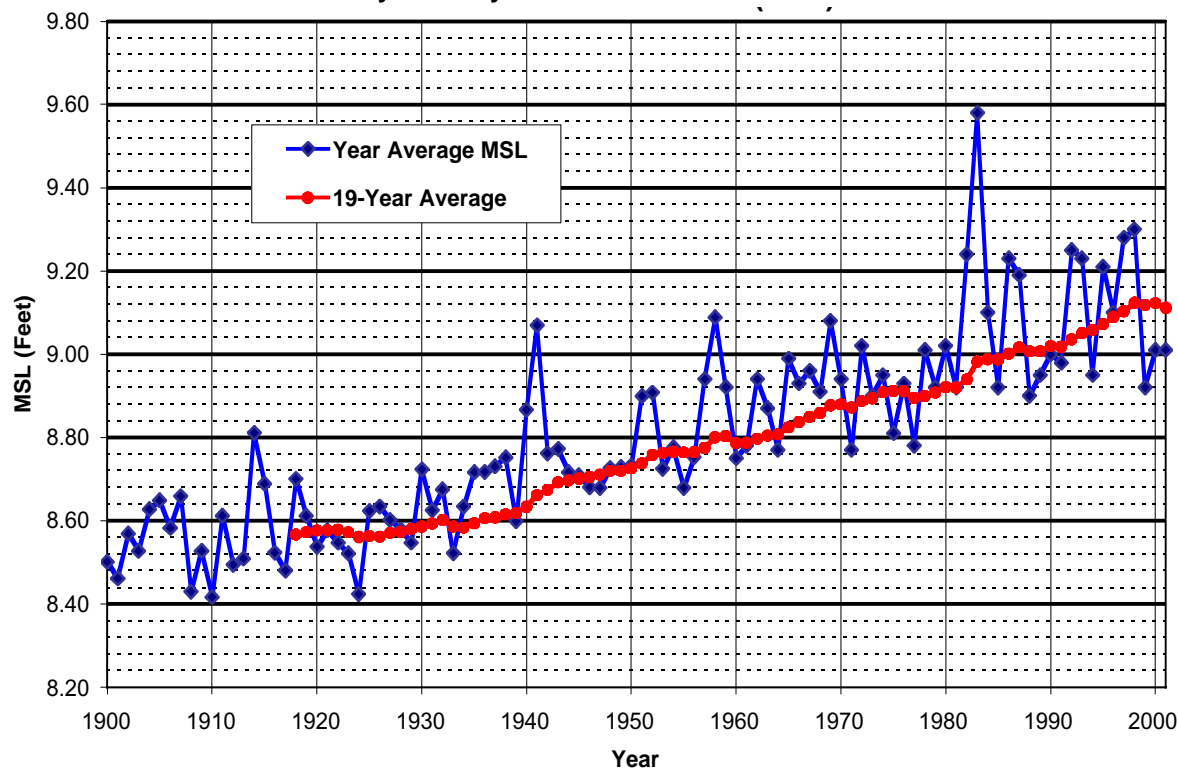


Figure 3:
Yearly and 19 year mean sea level at Golden Gate



There is a general expectation that a warmer climate would lead to more intense precipitation events, potentially causing somewhat bigger floods and more intense convective storms, thereby affecting the rainfall statistics used for storm drainage design. The IPCC report rates prediction confidence in more intense precipitation events as “very likely, over many areas”. A couple of recent research studies attempting to downscale global climate model results to the watershed scale in California indicated substantial increases in the size of floods

The increase in carbon dioxide, from the current 370 ppm to perhaps 600 or 700 ppm is expected to benefit growth of many food crops, provided the water supply is adequate and temperatures don’t get too hot. Higher carbon dioxide concentrations in the air could partly offset the higher water use (evapotranspiration) in agricultural production resulting from warmer temperatures.

Warmer air and less snowpack would be expected to raise average stream and estuary water temperatures. This would increase the problem for cold-water fisheries, including salmon and steelhead.

All of these projected changes, as well as some not yet identified, are likely to affect the hydrologic cycle and the water resources of California.

Major Consequences to Water Resources Systems

There are a large number of potential effects on California water resources infrastructure due to global warming. Much depends on the degree of warming and whether future changes are small or large. There are potential impacts on snowpack accumulation and melting, runoff patterns, water supply, sea level, floods and droughts, water demands, water temperature, plant and animal life including livestock, hydroelectric power, wild fires, recreation, water quality, soil moisture, groundwater, and ecosystems. Only five of these will be dealt with in the section: water supply, sea level rise, extremes (primarily floods), water requirements, and river water temperature.

Water Supply

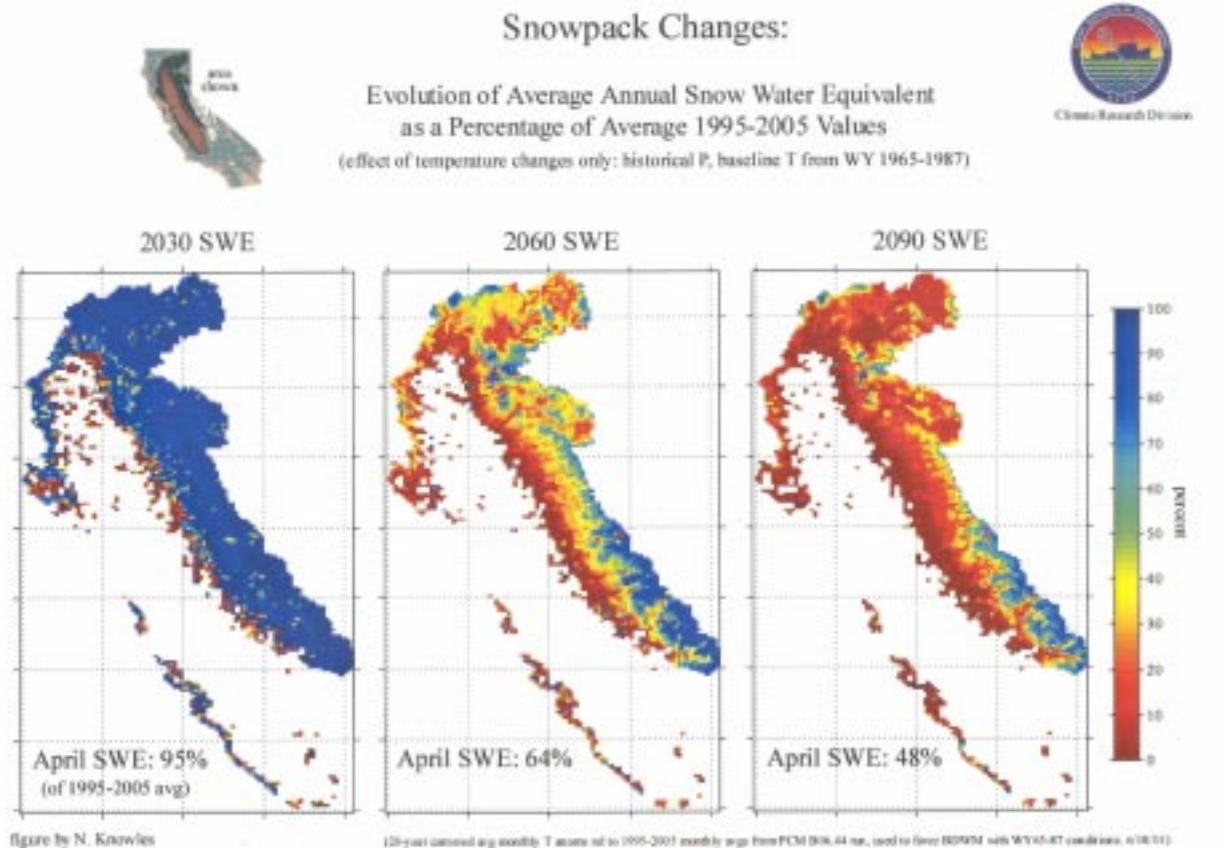
The most important parameter in determining runoff and therefore water supply is precipitation. Regional precipitation predictions in the huge general circulation models of the atmosphere have not been reliable, and vary greatly among the different models. As a general rule, a warmer world would mean more evaporation, hence more precipitation overall. But where and when the precipitations falls is all-important. Some researchers think that climate warming might push the winter storm track on the West Coast further north, which would mean a drier California. On the other hand, some of the new GCM’s, including the two used in the National Water Assessment, increase average California precipitation.

If warming occurs, one impact is considered relatively certain. On average, snow levels in the mountains will rise and the average amount of snow covered area and the snowpack will decrease. A reasonable estimate is about 500 feet of elevation change for every degree C rise. Many early studies, including the 1989 National Academy of Science report, have used 3°C as a benchmark of scenarios, which is still in the midrange of the new IPCC predictions, as a reasonable 100-year projection for the western states. This would mean a rise of about 1,500 feet in average snow levels. Historical average snow elevations on April 1 (the usual peak of the snow accumulation season) range from about 4,500 feet in the north above Shasta Lake to around 6,000 feet in the southern Sierra. Earlier DWR assessments some years ago came up with estimates for a rise of 1,500 feet in the average freezing level during storms and assuming the amount of

precipitation remained approximately the same. In the Sacramento River region, only about one fourth of the snow zone would remain with an estimated decrease of nearly 3 million acre-feet of April through July runoff. The impact would be much less in the higher elevation southern Sierra. About seven tenths of the San Joaquin/Tulare Lake region snow zone would stay.

Not all the spring runoff comes from melting snow. In the northern Sierra, spring rainfall is an important contributor. The estimated average reduction in Sacramento River region April through July runoff was projected to be 43 percent, leaving 57 percent of current runoff. The southern Sierra impact was less with 23 percent reduction overall. The total runoff reduction for all watersheds was 33 percent. These results were crude and preliminary, but have been roughly confirmed by more recent work by Scripps and others. A Knowles and Cayan study (Scripps, 2001) included a 2090 projection from the Parallel Climate Model with 2.1 degrees C (3.8 F) of warming to come up with a 50 percent reduction in April snow water content and a 4.5 million acre- foot reduction in April through July runoff.

Figure 4
Projected Snow Pack as a percentage of Average 1995-2005 (Knowles and Cayan)



Some GCM studies project significantly more winter season precipitation in California, some models are drier. It is possible for the southern Sierra snowmelt runoff to increase in the wetter scenarios, albeit from less area. All models so far show less snowmelt runoff in the northern Sierra.

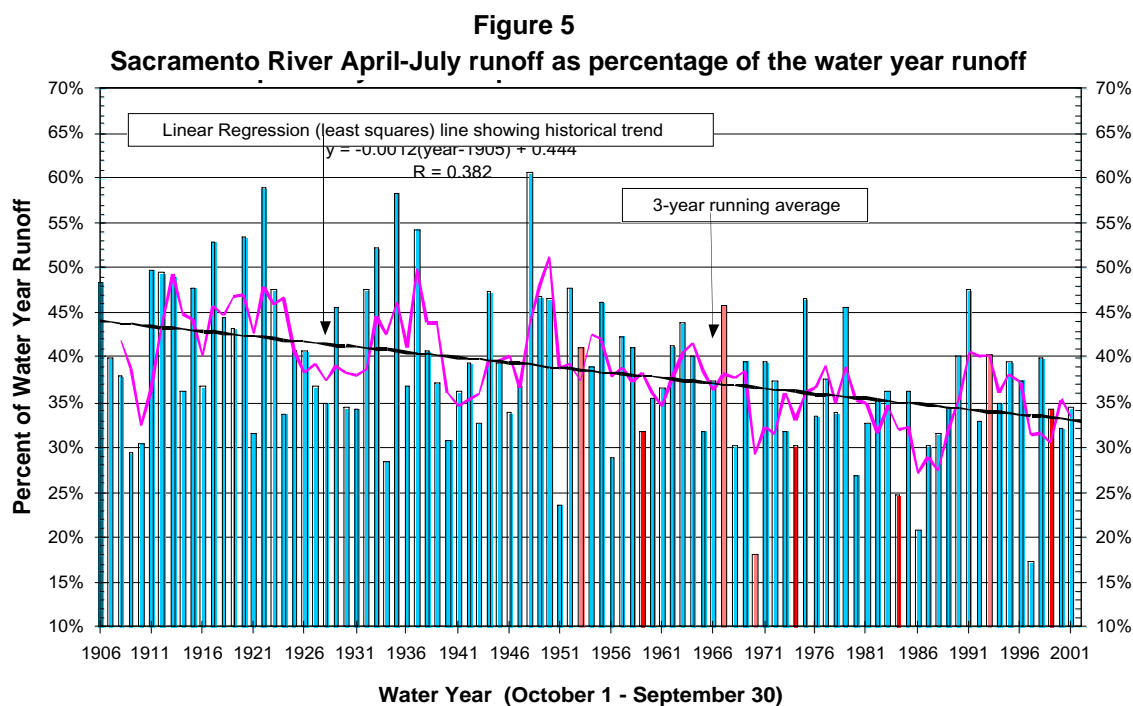
Less spring snowmelt could make it more difficult to refill winter reservoir flood control space during late spring and early summer of many years, thus potentially reducing the amount of surface water available

during the dry season. Lower early summer reservoir levels also would adversely affect lake recreation and hydroelectric power production, with possible late season temperature problems for downstream fisheries.

April-July runoff, primarily snowmelt, in California major rivers (including the Trinity River which supplies water to the Central Valley Project) amounts to about 14 million acre-feet on average. This is about 40 percent of the estimated total State net demand for agricultural and urban water use. Replacing that would take about 4 to 5 MAF of reservoir storage, increased conveyance facilities and other measures. Of course, if precipitation increases, reductions in runoff would be less, especially in the higher elevation southern Sierra.

Not all river systems would be equally affected; much depends on the existing storage capacity. One would expect only a slight impact on the Stanislaus River, for example, where the ratio of storage to average annual runoff is about 2.5 and winter spills on flood control releases are uncommon. The American River ratio is about 0.64 so it is likely to be more affected.

One can look at our recent hydrologic history to see if any trends are evident. The chart shows the record for the Sacramento River system for the 20th century. April through July runoff is plotted as a percentage of total water year runoff. There really was not much trend until the last half of the century, when the percentage of April through July runoff begins to show a progressive decline. Changes in North Pacific ocean current patterns, known as the Pacific Decadal Oscillation may explain part of the trend. The same effect is noted on the southern Sierra rivers, but the decrease is less. The same downward pattern in Sacramento River snowmelt runoff can be seen on a chart plotting volume with years, but the fit is poorer and a consistent trend not as evident.



Sea Level Rise

A second potential impact is sea level rise. This would lead eventually to problems in certain coastal areas with low-lying salt marshes and other lands protected by dikes. But the big impact on California water supply could be in the Sacramento-San Joaquin Delta. There the problem would be two-fold: (1) problems with the levees protecting the low-lying land, much already below sea level and (2) increased salinity intrusion from the ocean which could degrade fresh water transfer supplies pumped at the southern edge of the Delta or require more fresh water releases to repel ocean salinity.

Many of the central Delta levees are built on unstable peat soil and are vulnerable to high water peaks. The potential impact of sea level rise on these levees depends on the rate of increase. A small rise can probably be tolerated by the levee system; a major rise of one foot or more could cause significant problems. Extrapolating current trends yields about 0.4 foot by year 2050. The IPCC median projection is about 1.6 feet by 2100. One perspective is that a one-foot rise would transform the current 100-year high tide peak at Antioch, a western Delta station, into about a 10-year event. Thus the rare high event could become a more frequent threat to the Delta levees and the role they play in protecting the sensitive Delta.

Since California is tectonically active, it is the net combined effect of geologic change, rising or falling land, and sea level rise, which matters. The effect of a rising ocean would be magnified where land subsidence is occurring and decreased where uplift is happening.

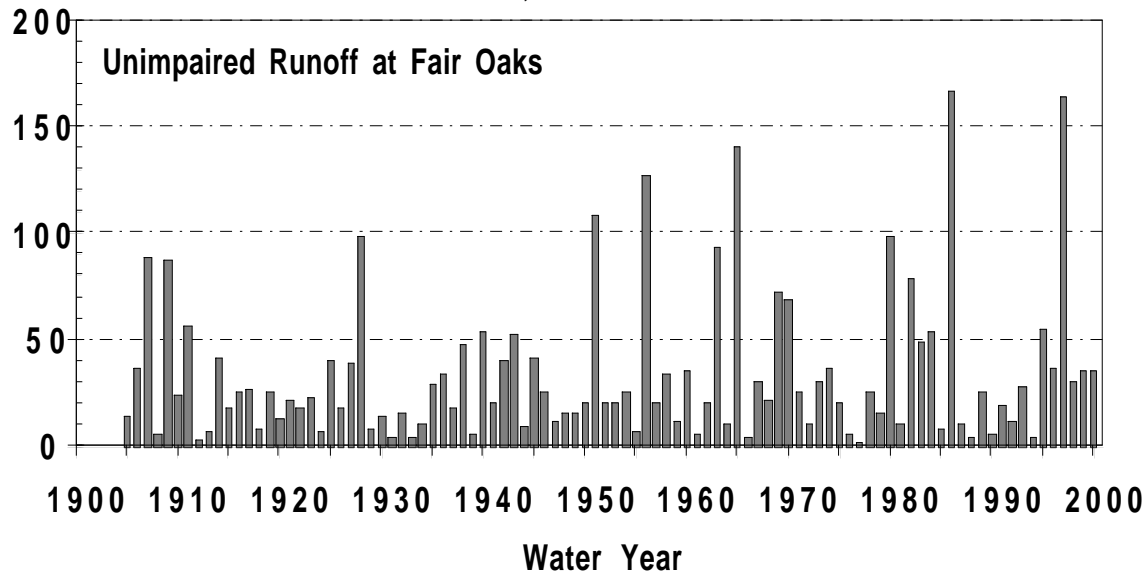
Salinity intrusion is a function of channel depth and time, increasing rapidly with depth. Climate change induced sea level rise could increase overall channel depths, potentially increasing salinity intrusion and diminishing water quality for south of Delta users. Reduced excess snowmelt in the spring would also mean a longer dry season, that is, more time, for saltwater intrusion. However, depths in the upper estuary and the western Delta may not change that much if the sea level rise is small.

More Extreme Events

A third possible effect could be more extreme events: (1) larger floods and more intense precipitation events, particularly if the wetter winter scenario of the National Water Assessment materializes, and (2) longer drier droughts if other model scenarios are considered.

There is a general relationship between rainfall intensity and the warmth of the climate. Other factors being equal, warm air holds more water vapor than cool air. For a given amount of lift of saturated air, more condensation will occur from warmer as compared to cooler air. Therefore, lifting of the air either orographically by winds blowing over a mountain range, by convective activity (thunderstorms), or by a weather system front has the potential for greater precipitation intensity. Also, higher snow levels in the Sierra Nevada and other high mountains mean more watershed area contributing direct rain runoff during winter storms and less snow accumulation.

Figure 6
American River Three Day Flood Bar Chart



Major floods on California's rivers are produced by slow moving Pacific storm systems, which sweep moist subtropical air from a southwesterly direction into the State. When these moisture-laden weather systems run into the mountains, copious amounts of rain and runoff are produced as the air is lifted by the mountain ranges. Whether the southwesterly winter storm winds would be stronger or weaker if global warming occurs has not been determined. In one simple experiment by the Department of Water Resources on the American River basin east of Sacramento, temperatures of a major storm (like that of February 1986) were raised three degrees Celsius, keeping the strength of the southwesterly winds and the relative humidity the same. The storm runoff increased about 10 percent. If storm intensities increase, it is likely the probable maximum flood used for dam spillway design would be bigger.

Research work by Dr. Michael Dettinger of Scripps Institution of Oceanography and Dr. Norman Miller and associates at Berkeley National Laboratory show an increased risk of large storms and flood events for several GCM scenarios. Since existing flood control facilities in the Central Valley and elsewhere seem to be barely able to accommodate large flood events, like the 1-in-100-year flood, even a modest increase could pose problems. An increase in winter flood control space would conflict with operations for water supply, power and recreation on many of the big multipurpose reservoirs in California. The total volume of maximum winter flood control space requirements on major Central Valley foothill reservoirs exceeds 5.5 million acre-feet.

Increasing winter flood control space generally would make it more difficult to fill reservoirs in the spring. The filling problem would be compounded if spring runoff were reduced because of smaller snowpacks.

Related to flood risk are the rainfall depth-duration-frequency data widely used for designing local storm water control and drainage facilities. It has been suggested that these statistics be updated frequently, at least every 20 years or so. In this way, climate changes will be gradually incorporated into the record and in the rainfall statistics.

Water Use

There are likely to be changes in water use as well as in water supply. Water consumption changes may be small, but because so much land area is involved, amounts could be very significant. Generally, a slightly warmer climate with less frost and a higher atmospheric concentration of carbon dioxide is regarded as beneficial to most food crops.

As a rule, plant evapotranspiration (ET) increases with temperature. Higher carbon dioxide levels, however, reduce water consumption (at least in laboratory tests), and seem to increase yield. In the opinion of knowledgeable researchers, the higher water consumption with warmer temperatures will probably only be partially offset by the carbon dioxide-based reductions. Thus, the net result could be slightly higher agricultural water requirements. Assessing the potential impacts to agriculture is complicated for some annual crops because it may be possible to change the planting season a few weeks, which may result in no net change in water use for that crop.

The whole subject of potential crop ET and water requirements is an important area of investigation for university and agriculture extension service people. In view of further cuts in water availability to California agriculture, changes in ET would be of great importance.

Warmer Water Temperature

Of considerable concern, if California temperatures rise significantly, would be managing salmon and steelhead fisheries. Warmer air temperatures will make it more difficult to maintain rivers cold enough for cold-water fish, including anadromous fish. With reduced snowmelt, existing cold-water pools behind major foothill dams are likely to shrink. As a result, river water temperature could warm beyond a point that is tolerable for the salmon and steelhead that currently stay in these rivers during the summer. Under this scenario, it is doubtful that the existing, cold-water temperature standards in the upper Sacramento River would be able to be maintained. Problems are likely for juvenile steelhead, as well.

A few of the major reservoirs have multilevel outlet structures able to control discharge water temperatures. For many of the others where downstream fisheries require cold water, temperature control structures should be considered and, where feasible, installed.

Colorado River Impacts

The Colorado River in recent years has furnished slightly over half of the total water supply for the South Coast and Colorado River regions of Southern California. With the planned reduction in California diversions to 4.4 million acre-feet it will still furnish about 45 percent of estimated current water demands, a very important portion of the State's water budget. Because total reservoir storage on the Colorado River exceeds 4 times the average annual runoff of about 15 million acre-feet, its water supplies are not very vulnerable to seasonal shifts in runoff due to less snowpack. Rather it is the total annual amount of runoff which matters. Most of the runoff is generated from a relatively small portion of the basin, on the order of 10 percent, which is the high elevation mountain region. Studies by Nash and Gleick (1993) indicate that percentage changes due to global warming may be somewhat less in the higher watersheds than when modeling the basin as a whole above Glen Canyon dam. Their 1993 report also indicates that about a 10 percent increase in precipitation would be required to offset the drying effect of about the same percentage due to a temperature rise of 2 degrees C.

Some GCM models show more precipitation in the Colorado River basin. Only a modest increase in runoff, on the order of 10 percent, can change the emphasis from water supply shortages to flood control. The message is that what happens on the Colorado River is very important to California, but more studies are needed to assess probable directions of impacts. A slightly drier scenario could rule out interim surplus over the 4.4 million acre-feet for California. Beyond that, under current law, further decreases in runoff would have to be absorbed by Arizona.

Adapting to Change

Even though there are large variances in GCM model results on certain parameters, such as likely future precipitation, some effects are consistent:

- Temperatures will rise, which will affect the extent and amount of winter snowpack in the mountains.
- However, the range in projections of the amount of temperature increase to expect is still quite large.
- Sea levels will rise with a likely minimum rate of 0.2 meter (0.7 feet) in the next century (the apparent recent historical rate) and possibly more.
- Some increase in the intensity of extreme precipitation and flood events is likely.
- Because of generally higher temperatures, some increase in crop and urban greenery water requirements is likely, but not large increases.
- River and estuary water temperatures will rise with increasing problems for cold water fisheries.

What We Need to Know

There are a number of needs for better information regarding climate change on which to base water resources planning. Foremost is better hydrologic monitoring so we can assess trends and changes which are underway. Because weather and hydrology are so inherently variable, many years of consistent and accurate measurements are vital. Besides indicating quantitative changes, the proposed monitoring is necessary feedback into calibrating climate models used for future predictions. Currently there are few good climate data stations in the mountain zones where the more significant changes are expected.

For water systems in California and elsewhere, climate model precipitation is probably the most important parameter. This must be developed at the watershed level for a representative set of future scenarios. The major tool for evaluating the impact on major water project systems would be the CALSIM reservoir system operation (simulation) model developed jointly by DWR and USBR. Development of modified monthly input to CALSIM from the climate models will require help from the research community. The heart of an adaptation program to improve the State's capacity to operate its complex water management system in the face of different and perhaps a more variable climate depends on assessing simulated operation over long hydrologic time periods. This would enable proactive planning and development of options and strategies to improve water supply and quality, including adapting to sea level rise in the Delta and possibly reoperation for flood control. Initial tests of the CVP-SWP system would more practically be based on a 50-year projection of trends during the past 50 years.

The December 2002 report of the California Floodplain Task Force did take note of the potential for bigger floods and changes in flood frequency with climate change. Conceivably, if more definite

estimates of these changes can be determined from further research with GCM results, some allowance for climate change can be built into the Task Force's concept of the "reasonably foreseeable flood."

Evaluation of major multipurpose reservoir flood control aspects is another major need, which would require generation of at least daily inflow from the watersheds. Linking climate and hydrologic models can provide such inflow, but is a major task. Some screening by climate model experts will be needed to select the climate models which can provide a more plausible future. Since the big floods are rare events, simulation of long periods of climate, thence runoff, and are required to develop confidence in results. Since there will be competition at the big multipurpose reservoirs between flood control and other purposes, a thorough examination of the flood space relaxation criteria in the spring would be in order. Possibilities of basing part of the flood space requirements on weather forecasts should be tested.

It is anticipated that changes in water requirements of crops, wildlands, and landscaping will be gradual. Some monitoring of reference evapotranspiration by renovating or reinstalling a few of the lysimeters which were operating in the 1960's is recommended to see if changes in the past 30 or 40 years are measurable. This would need to be a multi-year effort, possibly for 10 years, because of the variability from season to season.

While the evapotranspiration measurements are underway, it should be possible to convene a group or task force of knowledgeable experts on plant water consumption and agricultural practices by people from the university system and government. The goal would be to develop likely changes in evapotranspiration, and perhaps some ranges for year 2050 or 2100 scenarios, with warmer average temperatures and a higher carbon dioxide content of the atmosphere. To do this, some reasonable projections of future weather, including growing season precipitation are needed from the climate modelers. Some increase in plant water requirements would be expected because of warmer temperatures, but probably not a large percentage change.

The fifth major concern would be water temperature increases. There are existing models of water temperature which have been in use for a decade on some of the Sacramento River region major rivers. These models may need improvement as the job of maintaining suitable downstream temperatures becomes more difficult. Analysis of selected foothill reservoirs and rivers is suggested to see what a different pattern of inflow and higher air temperatures would do. New or upgraded temperature modeling is being developed as part of the Oroville power plant relicensing project. Once these tools are selected or developed, researchers can apply them to other streams and reservoirs. A logical extension would be to apply the new temperature models to evaluate the affect of a changed climate and runoff scenario, beginning with Lake Oroville and the Feather River.

The last item of strong interest would be effects of climate change in regions near California, especially the Colorado and Columbia River regions. The Colorado River would be most important to California because of potential impacts on water supply, with some potential effect on hydroelectric power. The Columbia River basin is an important source of electric power for California during the summer. If conditions there turned drier, there would be an impact on electricity as happened during 2001. For these basins, the best course of action for now may be to monitor results of anticipated new research and studies on runoff and water supply in both of these regions forthcoming by interested regional parties.

Summary

The preceding items are the major expected effects of global warming on the California water resources system. Climate change is just one of the factors water planners need to face in the coming century. Other factors include dealing with an expanding population, growth, environmental needs and maintaining the quality of land on water resources. Some degree of warming and sea level rise seem reasonably certain, but with the uncertainty of current climate model precipitation, the range of possible changes is quite large. There is serious scientific evidence that global warming will pose serious challenges to our water infrastructure. It is time to try to quantify the effects of projected climate change on California's water resources. Being aware of potential climate changes should help in preparing better for an uncertain 21st century.

History

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A California Water Chronology

In 2000, California celebrated its sesquicentennial (150 years of statehood). Within this relatively short time period, the State's major water infrastructure and complex institutional framework for managing water were developed. The following chronology highlights some key points in California's water history.

- 1848 Treaty of Guadalupe Hidalgo transfers California from Mexico to the U.S.
- 1848 Gold is discovered at Sutter's Mill on the American River.
- 1850 California is admitted to the Union.
- 1871 First reported construction of a dam on Lake Tahoe.
- 1884 Hydraulic mining is banned because of its impacts on navigation and contribution to flooding.
- 1886 *Lux v. Haggin* addresses competing water rights doctrines of riparianism and prior appropriation.
- 1887 Legislature enacts Wright Irrigation District Act, allowing creation of special districts.
- 1887 Turlock Irrigation District becomes first irrigation district formed under the Wright Act.
- 1895 World's first long-distance transmission of electric power (22 miles), from a 3,000 kW hydropower plant at Folsom to Sacramento.
- 1902 Congress enacts the Reclamation Act of 1902, creating the Reclamation Service, and authorizing federal construction of water projects.
- 1905 Salton Sea is created when the Colorado River breaches an irrigation canal and flows into the Salton Trough.
- 1913 First barrel of Los Angeles Aqueduct completed.
- 1914 California's present system of administering appropriative water rights is established by the Water Commission Act.
- 1922 Colorado River Compact signed.
- 1928 California Constitution amended to prohibit waste of water and to require reasonable beneficial use.
- 1928 Saint Francis Dam fails.
- 1929 State dam safety program goes into effect.
- 1929 East Bay MUD's Mokelumne River Aqueduct is completed.
- 1934 San Francisco's Hetch Hetchy Aqueduct is completed.
- 1940 All American Canal is completed.
- 1941 Colorado River Aqueduct is completed.
- 1945 Shasta Dam is completed.
- 1957 The Department publishes Bulletin 3, the California Water Plan.
- 1960 California voters approve the Burns-Porter Act, authorizing the sale of bonds to finance State Water Project construction.
- 1968 Oroville Dam is completed.
- 1968 Congress enacts National Wild and Scenic Rivers Act.
- 1969 Legislature enacts Porter-Cologne Act, the foundation of California water quality regulatory programs.
- 1969 Congress enacts National Environmental Policy Act.
- 1970 Legislature enacts California Environmental Quality Act.
- 1972 Legislature enacts California Wild and Scenic Rivers Act.
- 1973 California Aqueduct is completed.
- 1978 *California v. U.S.* held that the U.S. must obtain water rights under State law for reclamation projects, absent clear congressional direction to the contrary.

- 1978 SWRCB issues Decision 1485, requiring the CVP and SWP to meet specified Bay-Delta operating criteria.
- 1983 National Audubon Society v. Superior Court sets forth the application of public trust concepts to water rights administered by SWRCB.
- 1990 Congress enacts the Truckee-Carson-Pyramid Lake Water Rights Settlement Act (PL 101-618).
- 1992 Congress enacts the Central Valley Project Improvement Act (PL 102-575).
- 1994 SWRCB issues Decision 1631, requiring specified protections for Mono Lake levels.
- 1994 Bay-Delta Accord signed; its original three-year term extended to a total of four years.
- 1995 CALFED Bay-Delta Program to develop a comprehensive, long-term program for environmental protection of the Bay-Delta System and Water Supply and reliability for all water users. CALFED was charged with planning, selecting, and implementing this long-term solution.
- 1996 Monterey Amendments litigation filed against DWR. (Planning and Conservation League vs. Department of Water Resources and Central Coast Water Authority)
- 1997 Silverwood Lake celebrates Grand Reopening after the completion of new intake structure.
- 1998
- 1999
- 2000 CALFED publishes Programmatic Record of Decision
DWR begins collaborative, strategic planning process for *California Water Plan Update 2003*
- 2001
- 2002 Statement of principles for settlement of the Monterey Amendments litigation.
DWR seeks new license from Federal Energy Regulatory Commission to operate Oroville Facilities (FERC Project No. 2100) in Butte County.
- 2003 Inaugural meeting of the California Bay-Delta Authority, formerly known as CALFED. CBDA specifically is charged with ensuring balanced implementation of the CALFED Record of Decision.
Colorado River Quantification Settlement Agreement and Salton Sea ecosystem restoration legislation create new responsibilities for the Resources Agency and for the Departments of Fish and Game and Water Resources.
- 2004

Update of the California Water Plan

The California Water Plan (1957)

The California Water Plan was the final of a series of three bulletins setting forth the results of statewide water resources investigations which had begun in 1947. Bulletin No. 3 described a comprehensive master plan for the control, protection, conservation, distribution, and utilization of the waters of California, to meet present and future needs for all beneficial uses and purposes in all areas of the State to the maximum feasible extent. It was an ultimate plan that indicated the general manner in which California's water resources should be developed to satisfy the potential ultimate water requirements of the State. It did not give consideration to time or economics, either in staging of projects or in the growth of demand for water and associated services. It was to be regarded as a broad and flexible pattern into which future definite projects may be integrated in an orderly fashion. Additional data and experience not foreseen in 1957 would substantially alter and improve The California Water Plan. The basic concept of the Plan as a master plan to meet the ultimate requirements for water at some unspecified but distant time in the future, when the land and other resources of California have essentially reached a state of complete development, would remain unchanged. It was to be implemented by a statewide program for the construction of projects needed to control and supply water wherever and whenever the need arises and as projects are found feasible. The job would require the combined efforts of the federal government, state government and local agencies, as well as private entities and individuals, with the State taking a leading role in administration and coordination as well as financing and construction. The base year for Bulletin No. 3 was 1950.

Statewide planning studies to update the California Water Plan have continued since 1961, and have incorporated economic considerations. Results of the studies have been presented in the Bulletin 160 series of reports.

Implementation of the California Water Plan (1966)

The first of the Bulletin 160 series, Bulletin No. 160-66 reported on studies conducted within the framework of The California Water Plan, and outlined the manner by which progress should be made from the present (1960) to the stage of development that would meet the State's 2020 demands. It included the best available information on water demand forecasts throughout the State and on economic considerations involved in the staging of water supply and delivery projects. It identified some of the more favorable projects and presented a schedule for the staging of those projects to meet the increasing water demands. Bulletin No. 160-66 was neither an alternative nor a replacement of Bulletin 3, but rather a proposed pattern for implementation of specific parts of The California Water Plan, as set forth by the California Water Code.

Some water policy concerns discussed included flood control and floodplain management, power demands, water-related recreation, the relationship of fish and wildlife to water development, and water quality.

Water for California: The California Water Plan; Outlook in 1970

By 1967 California's population had grown to 19 million, but the rate of growth had slowed from that of the 1950s. In this Bulletin No. 160-70 population projections for 1990 and 2020 were reduced. Irrigated acreage estimates were also reduced, and more accurate information on the consumptive use of crops and the extent of water reuse was available. With projects then under construction or authorized, the report concluded that sufficient water supplies would be available to meet most of the 1990 requirements. The report concluded that the projected slower population growth, together with additional water supplies under development or authorized, would provide a breathing spell that would allow more time " . . . to consider alternative sources of water supply and develop policies for the maximum protection of the environment." The trend toward increasing environmental awareness was noted for both the national and State levels.

The California Water Plan: Outlook in 1974

By 1972, the base year for Bulletin 160-74, the State's population had reached about 21 million, indicating a continuing slowdown in the rate of growth. Population projections were again revised downward for 2990 and 2020 to 27 million and 37 million, respectively. This report concluded that the status of available supplies, compared to the (then) present use, was favorable. This was based on the premise that the Auburn, New Melones, and Warm Springs Reservoirs and the Peripheral Canal would be operational by 1980. But it was less conclusive about the extent to which supplies would satisfy future needs, considering new California legislation for wild and scenic rivers, primarily on the North Coast. Key water policy issues discussed were cooling water for electric energy production, water deficiencies (risk), water exchanges, public interest in agricultural drainage (San Joaquin Drain), water use efficiency (water conservation), economic efficiency (water transfers), and waste water reclamation.

This issue of the Bulletin 160 series departed from the earlier practice of a single forecast of future water use by presenting four different scenarios as to future conditions and events that affect water use.

The California Water Plan:

Projected Use and Available Water Supplies to 2010 (1983)

Bulletin 160-83 presented some of the alternative sources of supplies or potential shortages associated with future uses to 2010. More a technical report than previous editions, part of the process included the development of agricultural models applied for the first time. These were used in assessing the general economic effects of increasing water and energy costs. The report quantified the effect of urban and agricultural water conservation measures and the potential for water reclamation as a means of reducing water needs. A number of non-structural options for making more effective use of water supplies were proposed for further consideration.

California Water: Looking to the Future (1987)

Looking back to the previous four reports in the Bulletin 160 series, Bulletin 160-87 described them as technical examinations of the then-current water supplies and water demand for coming decades. The

1987 report took a broad view of water events and issues in California, and examined how California can continue to meet the water needs of a continually growing population. The report also discussed several leading water management concerns including water quality, the Sacramento-San Joaquin Delta, and evolving water policies over a wide range. One of its main conclusions was that in roughly three out of four years, California's natural water resources, including rights to the Colorado River, were sufficient to meet all of its water needs for the foreseeable future.

California Water Plan Update: Bulletin 160-93 (1994)

More than 35 years after the first California water Plan was published, this report discussed how population growth, land use, and water allocations for the environment were affecting water resource management. The bulletin discussed the effects of more stringent water quality standards, the Endangered Species Acts, the Central Valley Project Improvement Act of 1992, and efforts to solve problems in the San Francisco Bay-Sacramento-San Joaquin River Delta estuary. It differed from the five previous water plan updates by: (1) estimating environmental water needs separately and accounting for these needs along with urban and agricultural water demands; (2) presenting water demand management methods as additional means of meeting water needs; and (3) presenting separate water balance scenarios for average and drought conditions.

This was the first of the Bulletin 160 series to incorporate an Advisory Committee of representatives of interested parties. The base year for analysis was 1990, and 2020 was the planning horizon.

The California Water Plan Update: Bulletin 160-98 (1998)

In response to public comments on the previous Bulletin 160, the 1998 issue evaluated water management options that could improve California's water supply reliability. By 1995, locally developed water supplies represented 70 percent of California's total developed water supplies. Water management options being planned by local agencies form the building blocks for evaluations performed for each of the State's ten hydrologic regions. Potential local options were integrated with options of a statewide scope, such as the CALFED Bay-Delta Program, to create a statewide evaluation. Bulletin 160-98 estimated a 1.6 million acre-feet water shortage in average years at the 1995 level of development, and a 5.1 maf shortage in drought years.

Hydrology

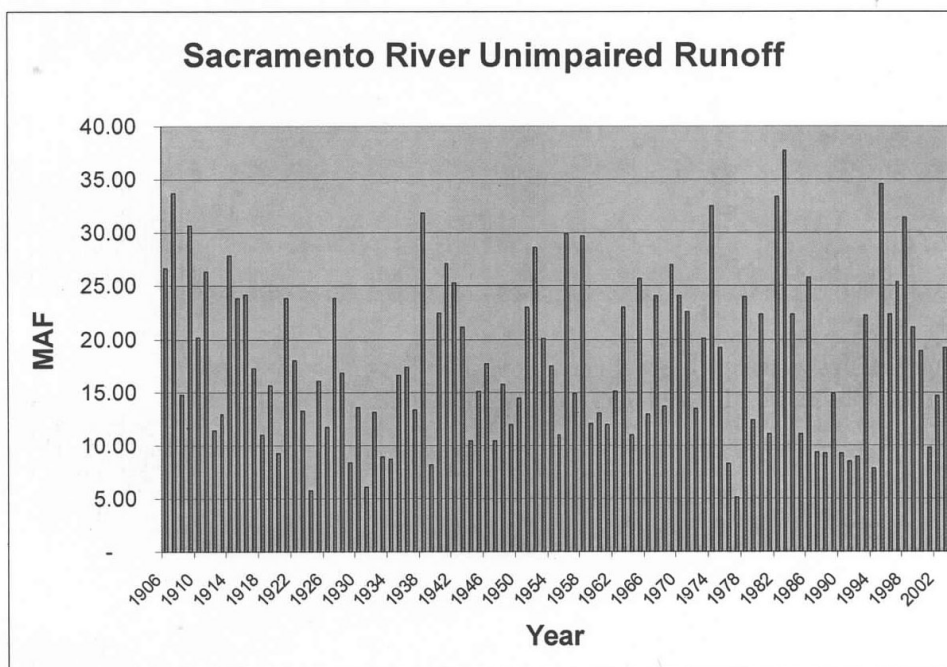
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California River Indices

Hydrology: California's water development has generally been dictated by extremes of droughts and floods. The six-year drought of 1929-34 established the criteria commonly used to plan storage capacity or water yield of large Northern California reservoirs. The influence of climatic variability on California's water supplies is much less predictable than the influences of geographic and seasonal variability, as evidenced by the recent historical records of precipitation and runoff. For example, the State's average annual runoff includes the all-time low of 15 maf in 1977 and the all-time high of over 135 maf in 1983. Floods and droughts occur often, sometimes in the same year. The January 1997 flood was followed by a record-setting dry period from February through June, and the flooding of 1986 was followed by six years of drought (1987-92).

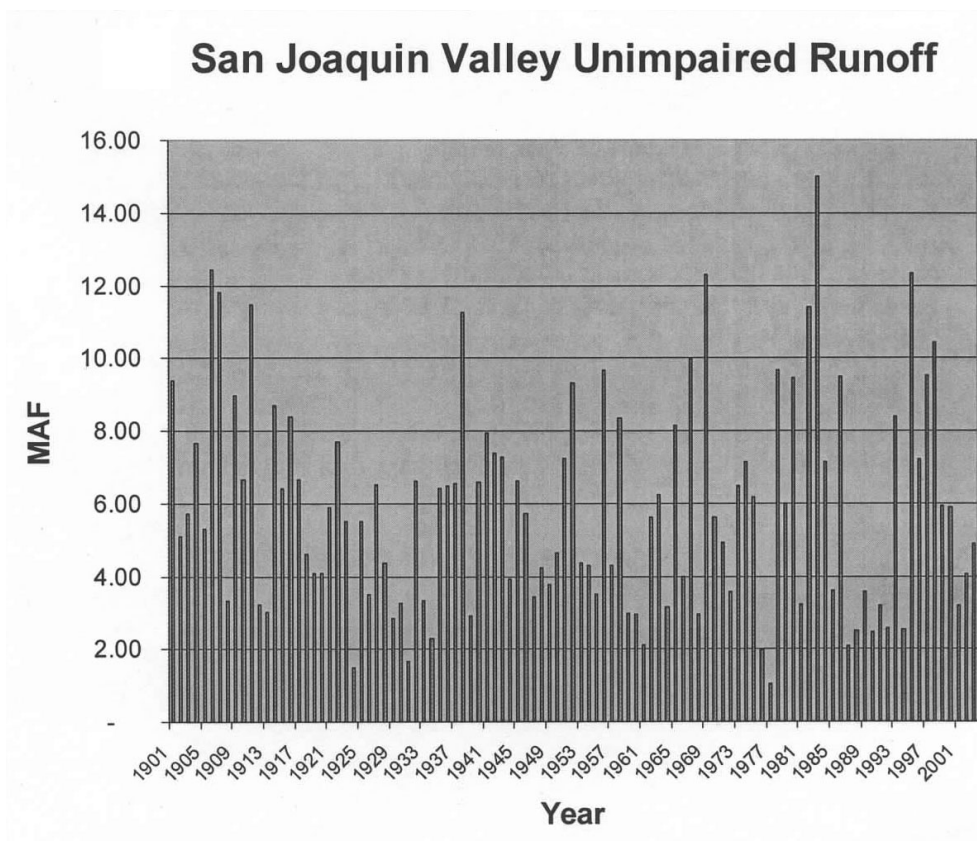
Figures showing the estimated annual unimpaired runoff of the Sacramento and San Joaquin River basins illustrate climatic variability. Because these basins provide much of the State's water supply, their hydrology is often used as indices of water year classification systems.

Unimpaired runoff represents the natural water production of a river basin, unaltered by upstream diversions, storage, and export of water to or import of water from other basins.



Unimpaired runoff represents the natural water production of a river basin, unaltered by upstream diversions, storage, export of water to or import of water from other basins.

Sacramento River Runoff is the sum (in maf) of Sacramento River at Bend Bridge, Feather River inflow to Lake Oroville, Yuba River at Smartville, and American River inflow to Folsom Lake. The water year sum is also known as the Sacramento River Index, and was previously referred to as the "4 River Index" or "4 Basin Index". It was previously used to determine year type classifications under SWRCB Decision 1485.



San Joaquin River Runoff is the sum of Stanislaus River inflow to New Melones Lake, Tuolumne River inflow to New Don Pedro Reservoir, Merced River inflow to Lake McClure, and San Joaquin River inflow to Millerton Lake (all in maf).

Water Year Classification: Water year classification systems provide a means to assess the amount of water originating in a basin. Because water year classification systems are useful in water planning and management, they have been developed for several hydrologic basins in California. The Sacramento Valley 40-30-30 Index and the San Joaquin Valley 60-20-20 Index were developed by the State Water Resources Control Board (SWRCB) for the Sacramento and San Joaquin River hydrologic basins as part of SWRCB's Bay-Delta regulatory activities. Both systems define one "wet" year classification, two "normal" classifications (above and below normal), and two "dry" classifications (dry and critical), for a total of five water year types.

Sacramento Valley Water Year Index = $(0.4) \times \text{Current Apr-Jul runoff forecast (in maf)} + (0.3) \times \text{Current Oct-Mar runoff (in maf)} + (0.3) \times \text{Previous Water Year's Index}$ (if the Previous Water Year's Index exceeds 10.0, then 10.0 is used).

This index, originally specified in the 1995 SWRCB Water Quality Control Plan, is used to determine the Sacramento Valley water year type as implemented in SWRCB D-1641. Year types are set by first of month forecasts beginning in February. Final determination is based on the May 1 50 percent exceedence forecast.

Sacramento Valley Water Year Hydrologic Classifications are:

| <u>Year Type</u> | <u>Water Year Index</u> |
|------------------|---|
| Wet | Equal to or greater than 9.2 |
| Above Normal | Greater than 7.8, and less than 9.2 |
| Below Normal | Greater than 6.5, and equal to or less than 7.8 |
| Dry | Greater than 5.4, and equal to or less than 6.5 |
| Critical | Equal to or less than 5.4 |

San Joaquin Valley Water Year Index = (0.6) x Current Apr-Jul runoff forecast (in maf) + (0.2) x Current Oct-Mar runoff (in maf) + (0.2) x Previous Water Year's Index (if the Previous Water Year's Index exceeds 4.5, the 4.5 is used).

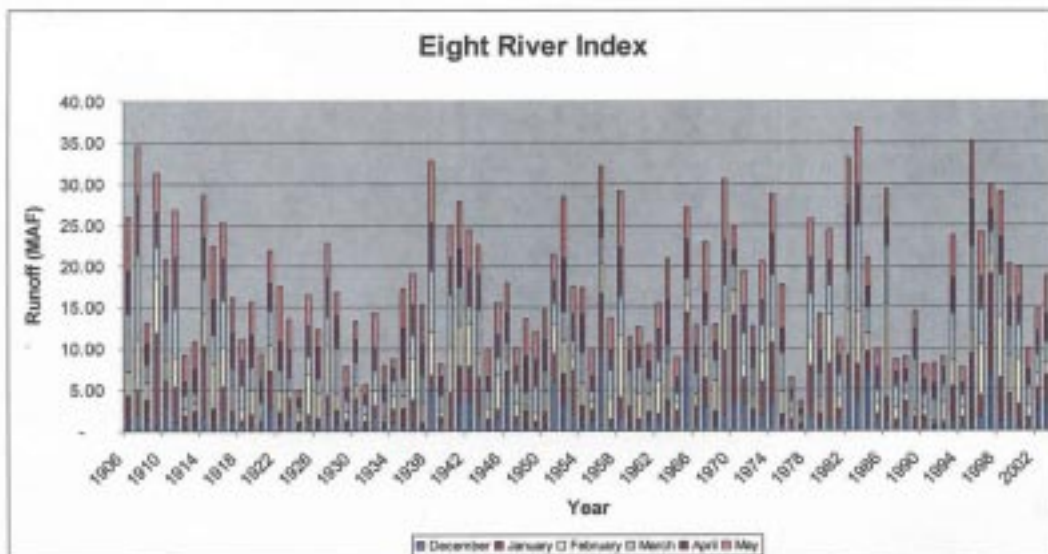
This index, originally specified in the 1995 SWRCB Water Quality Control Plan, is used to determine the San Joaquin Valley water year type as implemented in SWRCB D-1641. Year types are set by first of month forecasts beginning in February. Final determination for San Joaquin River flow objectives is based on the May 1 75 percent exceedence forecast.

San Joaquin Valley Water Year Hydrologic Classifications are:

| <u>Year Type</u> | <u>Water Year Index</u> |
|------------------|---|
| Wet | Equal to or greater than 3.8 |
| Above Normal | Greater than 3.1, and less than 3.8 |
| Below Normal | Greater than 2.5, and equal to or less than 3.1 |
| Dry | Greater than 2.1, and equal to or less than 2.5 |
| Critical | Equal to or less than 2.1 |

Eight River Index = Sacramento River Runoff + San Joaquin River Runoff.

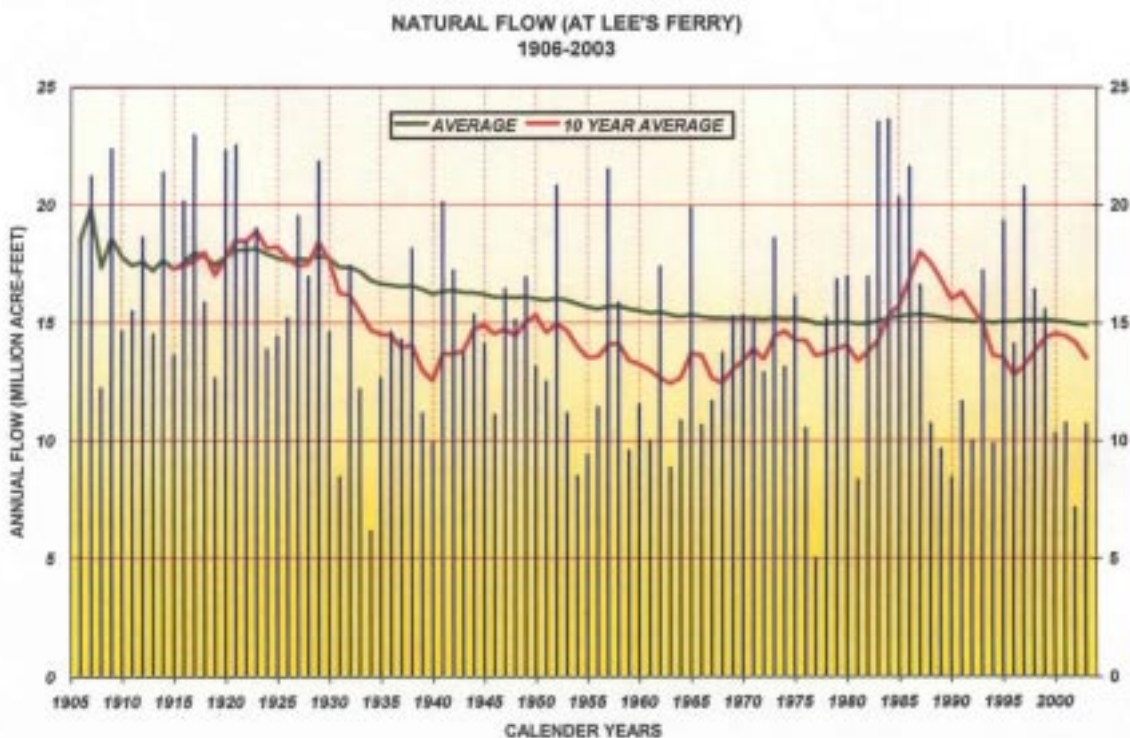
This Index is used from December through May to set flow objectives as implemented in SWRCB Decision 1641.



Colorado River

The Colorado River is an interstate and international river. Its mean annual unimpaired flow is about 15 maf. The river, which has its headwaters in Wyoming's Green River Basin, crosses through parts of seven states before flowing into Mexico and terminating at the Gulf of California.

Defining a representative drought in Southern California is complicated by the region's access to imported supplies from the Colorado River. Three major facilities—USBR's All American Canal, MWDSC's Colorado River Aqueduct, and Palo Verde Irrigation District's main canal—convey water from the Colorado River to California users. The Colorado River watershed is large (about 244,000 square miles, or roughly 10 times the size of the Sacramento River watershed) and experiences hydrologic conditions different than California's. As a result, Southern California's water supply may be buffered from the effects of severe drought in Northern California. The following figure presents Colorado River unimpaired flow at the Lee Ferry interstate compact measurement point to illustrate the river basin's hydrology.



Frequency of a 100-Year Flood

By Definition

Probability of a 100-Year Flood occurring in a given year = $1/100$

Therefore

Probability of a 100-Year Flood Not occurring in a given year = $(1 - 1/100)$

Probability of a 100-Year Flood Not occurring in 30 years = $(1 - 1/100)^{30} = 0.7397$

Therefore

Probability of a 100-Year Flood occurring at least once in the next 30 Years = $1 - 0.7397 = \underline{\underline{26\%}}$

Many Californians have a false sense of safety from floods, the result of incomplete information. Current flood threats are higher than commonly thought; the term “100-year flood,” for example, is misleading. It does not denote a flood that will occur only once every 100 years, as is commonly believed. Rather, it is the flood elevation (or flow) that has a one-percent chance of being equaled or exceeded each year. “Over the lifetime of a 30-year mortgage, there is a 26-percent chance of being flooded by a 100-year flood.”

Major Floods Since 1950

Wet water years are not necessarily indicative of flood conditions. Although water year 1983 was the wettest in California this century, major flooding did not occur. The following table shows estimated unimpaired runoff from a few of the State's larger floods since the 1950s. In January 1997, California confronted one of the largest and most extensive flood disasters in its history. Rivers across the State from the Oregon border to the southern Sierra reached flood stages. Flood volumes of some rivers exceeded channel capacities by as much as 700 percent. In many major river systems, flood control dams reduced peak flows by one-half or more. Even so, leveed flood control systems were overwhelmed in some areas. Flood damage costs are nearing \$2 billion.

| Unimpaired Runoff | | | | |
|-------------------|-------------------|----------|-----------------|--------------------|
| River | Location | Date | Max 1-Day (cfs) | 3-day Volume (taf) |
| Sacramento | Shasta Dam | Jan 1974 | 196,000 | 779 |
| | | Feb 1986 | 126,000 | 681 |
| | | Jan 1997 | 216,000 | 1,000 |
| Feather | Oroville Dam | Dec 1964 | 179,000 | 984 |
| | | Feb 1986 | 217,000 | 1,113 |
| | | Jan 1997 | 298,000 | 1,392 |
| Yuba | Marysville | Dec 1964 | 144,000 | 703 |
| | | Feb 1986 | 142,000 | 729 |
| | | Jan 1997 | 161,000 | 736 |
| American | Folsom Dam | Dec 1964 | 183,000 | 835 |
| | | Feb 1986 | 171,000 | 988 |
| | | Jan 1997 | 249,000 | 977 |
| Mokelumne | Camanche Dam | Dec 1964 | 36,000 | 171 |
| | | Feb 1986 | 28,000 | 149 |
| | | Jan 1997 | 76,000 | 233 |
| Stanislaus | New Melones Dam | Dec 1964 | 44,000 | 198 |
| | | Feb 1986 | 40,000 | 246 |
| | | Jan 1997 | 73,000 | 298 |
| Tuolumne | New Don Pedro Dam | Dec 1964 | 73,000 | 306 |
| | | Feb 1986 | 53,000 | 294 |
| | | Jan 1997 | 120,000 | 548 |

| | | | | |
|-------------|------------------------|----------|---------|-------|
| Merced | New Exchequer Dam | Dec 1964 | 33,000 | 136 |
| | | Feb 1986 | 30,000 | 164 |
| | | Jan 1997 | 67,000 | 262 |
| San Joaquin | Friant Dam | Feb 1986 | 33,000 | 176 |
| | | Mar 1995 | 39,000 | 156 |
| | | Jan 1997 | 77,000 | 313 |
| Truckee | Reno | Oct 1963 | 25,000 | 79 |
| | | Feb 1986 | 22,000 | 112 |
| | | Jan 1997 | 37,000 | 148 |
| Cosumnes | Michigan Bar | Dec 1964 | 29,000 | 115 |
| | | Feb 1986 | 34,000 | 196 |
| | | Jan 1997 | 60,000 | N/A |
| Eel | Scotia | Dec 1964 | 648,000 | 2,936 |
| | | Feb 1986 | 304,000 | 1,515 |
| Santa Ynez | Lompoc ^a | Jan 1969 | 38,000 | 175 |
| Salinas | Spreckles ^a | Feb 1969 | 65,000 | 252 |
| | | Mar 1983 | 60,000 | 314 |
| | | Mar 1995 | 64,000 | 241 |
| Santa Clara | Saticoy | Feb 1969 | 92,000 | 270 |

^a Impaired flows

Severity of Extreme Droughts in Sacramento and San Joaquin Valley

Numerous multi-year droughts have occurred in California this century: 1912-13, 1918-20, 1922-24, 1929-34, 1947-50, 1959-61, 1976-77, and 1987-92. In order to provide water supply reliability, major reservoirs are designed to maintain and deliver carryover storage through several years of drought. The 1929-34 drought established the criteria commonly used to design the storage capacity and water yield of large Northern California reservoirs. Many reservoirs built since this drought were sized to maintain a reliable level of deliveries should a repeat of the 1929-34 hydrology occur. Even a single critical runoff year such as 1977 can be devastating to water users with limited storage reserves, who are more dependent on annual runoff. Following table compares the severity of recent droughts with the 1929-34 drought in the Sacramento Valley and San Joaquin Valley.

| Drought Period | Sacramento Valley Runoff | | San Joaquin Valley Runoff | |
|----------------|--------------------------|---------------------|---------------------------|---------------------|
| | (maf/yr) | (% Average 1901-96) | (maf/yr) | (% Average 1906-96) |
| 1929-34 | 9.8 | 55 | 3.3 | 57 |
| 1976-77 | 6.6 | 37 | 1.5 | 26 |
| 1987-92 | 10.0 | 56 | 2.8 | 47 |

Groundwater supplies about 30 percent of California's urban and agricultural applied water use. In drought years when surface water supplies are reduced, groundwater supports an even greater percentage of use, resulting in declining groundwater levels in many areas. For example, during the first five years of the 1987-92 drought, groundwater extractions exceeded groundwater recharge by 11 maf in the San Joaquin Valley. Drawing down groundwater reserves in drought years is analogous to reservoir carryover storage operations.

Infrastructure

| | |
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California Reservoir Summary

The following table is a compilation of Calif. Reservoirs with a gross storage capacity of 10,000 acre feet or greater. Information given in the table is: location by Hydrologic Region, storage capacity, project uses, owner and year completed. The data came from the latest Bulletin 17-00, dated July 2000, titled “DAMS Within Jurisdiction of the State of California”. Several additional reservoirs that have been constructed since publication of Bulletin 17-00 have been added. Corrections have been made to the data where necessary if published data is not current. Please note that storage values include dead storage.

CALIFORNIA RESERVOIRS

(Over 10,000 AF Capacity)

NOTE: key to abbreviations used is at bottom of table.

| Reservoir (Dam) Name | Hydro. Region | Res. Capacity (TAF) | | Project Uses | | Owner | Year Comp |
|-----------------------------------|---------------|---------------------|----------------|----------------------|-------|--------------------------|-----------|
| | | >100 TAF | >10 & <100 TAF | Conservation Storage | Other | | |
| Olivenhain | SC | | 24 | M | | San Diego Co WA | 2003 |
| Diamond Valley | SC | 800 | | IM | R | MWD | 2000 |
| Seven Oaks (flood control) | SC | 145 | | | F | USCE | 2000 |
| Los Vaqueros | SF | 100 | | M | | Contra Costa Co. WD | 1998 |
| Big Dry Creek (modified) | SJ | | 30 | | F | Fresno Met. Flood C.D. | 1993 |
| New Spicer Meadow | SJ | 189 | | IM | P | CCWD | 1989 |
| Ramona | SC | | 12 | M | | Ramona MWD | 1988 |
| San Justo | CC | | 10 | I | | USBR | 1985 |
| Sonoma Lake (Warm Springs) | NC | 381 | | IM | FPR | USCE | 1982 |
| New Melones Lake | SJ | 2,420 | | IM | FPR | USBR | 1979 |
| Soulajule | SF | | 10 | M | R | Marin MWD | 1979 |
| Los Angeles Res. | SC | | 10 | M | | City of LA | 1977 |
| Upper San Leandro(New Upper S.L.) | SF | | 41 | M | | EBMUD | 1977 |
| Indian Valley Res. | SR | 301 | | IM | FPR | YCFCWCD | 1976 |
| Eastman Lk, H.V. (Buchanan) | SJ | 150 | | I | FR | USCE | 1975 |
| Hensley Lake (Hidden) | SJ | | 90 | I | FR | USCE | 1975 |
| Elderberry F.B. | SC | | 28 | | F | LADWP | 1974 |
| Castaic Lake | SC | 324 | | IM | PR | DWR | 1973 |
| Lake Perris | SC | 131 | | IM | PR | DWR | 1973 |
| Pyramid Lake | SC | 171 | | IM | PR | DWR | 1973 |
| Lake Skinner (Robert A. Skinner) | SC | | 44 | M | | Eastern MWD | 1973 |
| Martis | NL | | 20 | | FR | USCE | 1972 |
| Silverwood Lake(Cedar Springs) | SL | | 75 | M | PR | DWR | 1971 |
| Mojave River Forks Res | SL | | 90 | | F | USCE | 1971 |
| New Don Pedro Res(Don Pedro) | SJ | 2,030 | | I | FPR | TID-MID | 1971 |
| Bullards Bar (New Bullards Bar) | SR | 966 | | IM | FPR | YCWA | 1970 |
| Stampede Res. | NL | 226 | | M, 2 | FPAR | USBR | 1970 |
| Lake Siskiyou (Box Canyon) | SR | | 26 | M | F | Siskiyou Co FCWCD | 1969 |
| Lopez | CC | | 52 | M | F | San Luis Obispo Co FCWCD | 1969 |
| Lake Del Valle | SF | | 77 | M | FR | DWR | 1968 |

| | | | | | | | |
|-----------------------------------|----|-------|----|-----|------|-----------------------|------|
| Lake Oroville | SR | 3,538 | | IM | FPAR | DWR | 1968 |
| Lake McClure (New Exchequer) | SJ | 1,024 | | I | FPR | MID | 1967 |
| O'Neill Forebay | SJ | | 56 | IM | PR | USBR/DWR | 1967 |
| San Luis (BF Fisk) | SJ | 2,028 | | IM | PR | USBR/DWR (966/1062) | 1967 |
| Slab Creek Res. | SR | | 17 | | PR | SMUD | 1967 |
| Thermalito System | SR | | 81 | | PR | DWR | 1967 |
| Hell Hole (Lower Hell Hole) | SR | 208 | | IM | PR | PCWA | 1966 |
| Lake Davis (Grizzly Valley) | SR | | 84 | M | AR | DWR | 1966 |
| Senator Wash (regulating res) | CR | | 14 | I,3 | | USBR | 1966 |
| Bard Lake (Wood Ranch) | SC | | 10 | M | | Calleguas MWD | 1965 |
| French Meadows(L.L. Anderson) | SR | 136 | | IM | PR | PCWA | 1965 |
| Iron Canyon | SR | | 24 | | PR | PG&E | 1965 |
| Jackson Meadows | SR | | 69 | IM | PR | Nevada ID | 1965 |
| Lake Amador (Jackson Cr.) | SJ | | 22 | I | R | Jackson Valley ID | 1965 |
| Los Banos Det. | SJ | | 35 | M | FR | USBR/DWR | 1965 |
| McCloud | SR | | 35 | | PR | PG&E | 1965 |
| Pit #6 | SR | | 16 | | P | PG&E | 1965 |
| Pit #7 | SR | | 35 | | P | PG&E | 1965 |
| Rollins | SR | | 66 | I | PR | Nevada ID | 1965 |
| San Antonio | CC | 330 | | IM | P | MCWRA | 1965 |
| Antelope Lake | SR | | 23 | | RA | DWR | 1964 |
| Briones | SF | | 60 | M | | EBMUD | 1964 |
| San Antonio Res (James H. Turner) | SF | | 50 | M | | San Francisco | 1964 |
| Black Butte Lake | SR | 144 | | I | FPR | USCE | 1963 |
| Camanche Res | SJ | 417 | | I | FPR | EBMUD | 1963 |
| Camp Far West | SR | 104 | | I | PR | SSWD | 1963 |
| Lewiston Res. | NC | | 15 | | PR | USBR | 1963 |
| Loon Lake | SR | | 76 | M | PR | SMUD | 1963 |
| Merle Collins (Virginia Ranch) | SR | | 57 | I | R | Browns Valley ID | 1963 |
| New Hogan Res. | SJ | 317 | | IM | FPR | USCE | 1963 |
| Union Valley Res. | SR | 277 | | | PR | SMUD | 1963 |
| Villa Park | SC | | 16 | M | | Orange Co. MWD | 1963 |
| Whiskeytown Lake | SR | 241 | | I | PR | USBR | 1963 |
| Trinity Lake | NC | 2,448 | | IM | PR | USBR | 1962 |
| Hernandez | CC | | 18 | | F | San Benito Co FCWCD | 1962 |
| Iron Gate | NC | | 58 | | PR | Pacific Power & Light | 1962 |
| Lake Kaweah (Terminus) | TL | 143 | | I | FPR | USCE | 1962 |
| Prosser Creek Res. | NL | | 30 | I | FAR | USBR | 1962 |
| Ruth Lake (Robert W. Mathews) | NC | | 52 | M | PR | Humboldt Bay MWD | 1962 |
| Stumpy Meadows Res. (Mark Edson) | SR | | 20 | | PR | Georgetown Divide PUD | 1962 |
| Frenchman Lake | SR | | 55 | I | R | DWR | 1961 |
| Little Grass Valley | SR | | 95 | IM | PR | Oroville Wyandotte ID | 1961 |
| Nicasio | SF | | 22 | M | | Marin MWD | 1961 |
| Sly Creek | SR | | 66 | IM | P | Oroville Wyandotte ID | 1961 |
| Success Lake | TL | | 82 | I | FPR | USCE | 1961 |
| Mammoth Pool | SJ | 123 | | | P | SCE | 1960 |
| Whale Rock | CC | | 41 | M | P | Whale Rock | 1960 |

| | | | | | | Commission | |
|---|----|-------|----|---------------|------|----------------------------------|------|
| Ice House Res. | SR | | 46 | | PR | SMUD | 1959 |
| Lake Casitas | SC | 254 | | IM | R | USBR | 1959 |
| Lake Mendocino (Coyote Valley) | NC | 122 | | M | FPR | USCE | 1959 |
| Courtright Res. | TL | 123 | | | P | PG&E | 1958 |
| Donnell Res. | SJ | | 64 | I | P | Oakdale/So San Joaq ID | 1958 |
| Tulloch Lake | SJ | | 67 | I | PR | Oakdale/ So.SanJoaq.ID | 1958 |
| Twitchell Res. | CC | 240 | | grd wtr rech. | FR | USBR | 1958 |
| Wishon Res. | TL | 128 | | | P | PG&E | 1958 |
| Beardsley Lake | SJ | | 98 | I | P | Oakdale/So.SanJoaq. ID | 1957 |
| Lake Berryessa (Monticello) | SR | 1,600 | | IM | PAR | USBR | 1957 |
| Nacimiento | CC | 340 | | IM | P | MCWRA | 1957 |
| Paradise | SR | | 11 | M | | Paradise ID | 1957 |
| Uvas | SF | | 10 | M | | Santa Clara Valley WD | 1957 |
| Whittier Narrows F.C. Basin | SC | | 67 | | F | USCE | 1957 |
| Folsom Lake | SR | 977 | | IM | FPR | USBR | 1956 |
| Lloyd (Cherry)Lake (Cherry Valley) | SJ | 268 | | M | PR | San Francisco | 1956 |
| Jenkinson Lake (Sly Park) | SJ | | 41 | IM | PR | USBR | 1955 |
| Lake Piru (Santa Felicia) | SC | | 88 | M | | United WCD | 1955 |
| Kent Lake (Peters) | SF | | 33 | M | | Marin MWD | 1954 |
| Lake Thomas A. Edison, (Vermillion Valley) | SJ | 125 | | | P | SCE | 1954 |
| Pine Flat Lake | TL | 1,000 | | I | FPR | USCE | 1954 |
| Sutherland | SC | | 30 | M | | San Diego City | 1954 |
| Cachuma (Bradbury) | CC | 190 | | IM | R | USBR | 1953 |
| Isabella Lake | TL | 568 | | I | FPR | USCE | 1953 |
| Lexington | SF | | 20 | M | R | Santa Clara Valley WD | 1953 |
| Lower Bear River | SJ | | 52 | | PR | PG&E | 1952 |
| Farmington | SJ | | 52 | | FI | USCE | 1951 |
| Redinger Lake (Big Creek #7) | SJ | | 35 | | P | SCE | 1951 |
| Keswick | SR | | 24 | | PR | USBR | 1950 |
| Leroy Anderson | SF | | 90 | M | PR | Santa Clara Valley WD | 1950 |
| Santa Fe F.C. Basin | SC | | 32 | | F | USCE | 1949 |
| Vail Lake | SC | | 51 | M | | Rancho Calif. WD | 1949 |
| Mariposa | SJ | | 15 | | F | USCE | 1948 |
| Scotts Flat | SR | | 49 | I | PR | Nevada ID | 1948 |
| Millerton Lake (Friant) | SJ | 520 | | IM | FPR | USBR | 1947 |
| Lake Hennessey (Conn Cr.) | SF | | 31 | M | | City of Napa | 1946 |
| Lake Loveland | SC | | 25 | M | | National City(SweetwaterAuth) | 1945 |
| Shasta Lake | SR | 4,552 | | I | FPAR | USBR | 1945 |
| San Vicente | SC | | 90 | M | | San Diego City | 1943 |
| Santa Margarita Lake (Salinas) | CC | | 23 | M | | USCE | 1942 |
| Englebright Debris Dam | SR | | 70 | | D P | USCE(Calif Debris Com) | 1941 |
| Lake Crowley (Long Valley) | SL | 183 | | M | | LADWP | 1941 |
| Prado F.C. Basin | SC | 212 | | | F | USCE | 1941 |
| Sepulveda F.C. Basin | SC | | 17 | | F | USCE | 1941 |

| | | | | | | | |
|--------------------------------------|----|-------|----|----|-------|------------------------------|------|
| Grant Lake | SL | | 48 | M | PR | LADWP | 1940 |
| Hansen | SC | | 25 | | F | USCE | 1940 |
| Boca Res. | NL | | 41 | I | FRA | USBR | 1939 |
| Clementine Lk.(North Fork) | SR | | 14 | | D R | USCE (Calif Debris Com) | 1939 |
| Independence Lake | NL | | 18 | I | R | WESPAC Util. | 1939 |
| Copper Basin | SC | | 22 | M | | MWD | 1938 |
| Havasu Lake (Parker) | CD | 619 | | IM | PR, 2 | USBR | 1938 |
| San Gabriel No.1 | SC | | 42 | M | P | LA Co. Flood Control Dist | 1938 |
| Coyote | SF | | 23 | M | R | Santa Clara Valley WD | 1936 |
| West Valley | SR | | 22 | I | R | South Fork ID | 1936 |
| Morris | SC | | 27 | M | | MWD | 1935 |
| Bouquet Res.(Bouquet Canyon) | SC | | 34 | M | | City of LA | 1934 |
| El Capitan | SC | 113 | | M | | San Diego City | 1934 |
| Irvine Lake (Santiago Cr.) | SC | | 25 | IM | | Serrano ID/ Irvine R'ch WD | 1933 |
| Salt Springs | SJ | 142 | | | PR | PG&E | 1931 |
| Dorris | SR | | 11 | | A | USFWS | 1930 |
| Pardee | SJ | 198 | | M | PR | EBMUD | 1929 |
| Bucks Lake (Bucks Storage) | SR | 106 | | | PR | PG&E | 1928 |
| Lake Shastina (Dwinell or Shasta Rv) | NC | | 50 | I | P | Montague WCD | 1928 |
| Pudding Stone | SC | | 16 | M | | LADWP | 1928 |
| Railroad Canyon | SC | | 12 | M | | Temescal Wtr. Co. | 1928 |
| Stony Gorge Res. | SR | | 50 | I | PR | USBR | 1928 |
| Tinemaha | SL | | 6 | M | PR | LADWP | 1928 |
| Bowman Lake | SR | | 68 | IM | PR | Nevada ID | 1927 |
| Donner Lake | NL | | 11 | M | R | WESPAC Util. | 1927 |
| Lake Almanor | SR | 1,143 | | | PR | PG&E | 1927 |
| Shaver Lake | SJ | 135 | | | P | SCE | 1927 |
| Florence Lake | SJ | | 65 | | P | SCE | 1926 |
| Lake Curry | SF | | 10 | M | | City of Vallejo | 1926 |
| Lake Fordyce | SR | | 49 | | P | PG&E | 1926 |
| Calaveras | SF | | 97 | M | | San Francisco | 1925 |
| Lake Britton (Pit #3) | SR | | 41 | | PR | PG&E | 1925 |
| Bridgeport Res. | NL | | 43 | I | R, 2 | Walker Rv. ID | 1924 |
| Butt Valley | SR | | 50 | | P | PG&E | 1924 |
| Mountain Meadows (Indian Ole) | SR | | 24 | | P | PG&E | 1924 |
| Stone Canyon (Lower) | SC | | 10 | M | | City of LA | 1924 |
| Henshaw | SC | | 52 | IM | | Bueno Colo MWD (Vista ID) SD | 1923 |
| Hetch Hetchy(O'Shaughnessy) | SJ | 360 | | M | P | San Francisco | 1923 |
| Barrett | SC | | 38 | M | | San Diego City | 1922 |
| Caples Lake | SR | | 22 | | PR | PG&E | 1922 |
| Copco Lake (Copco #1) | NC | | 47 | | P | Pacific Power & Light | 1922 |
| Lake Arrowhead | SC | | 48 | M | R | Crestline Arrowhead OWR | 1922 |
| Big Sage | SR | | 77 | I | | Hot Springs Valley ID | 1921 |
| Lake Pillsbury (Scott) | NC | | 80 | | PR | PG&E | 1921 |
| Saddlebag Lake | SL | | 11 | | P | SCE | 1921 |

| | | | | | | | |
|-----------------------------------|----|--------------|-------------|-------|-------|--------------------------|------|
| San Pablo | SF | | 39 | M | R | EBMUD | 1920 |
| Lower Otay (Savage) | SC | | 50 | M | | City of San Diego | 1919 |
| Lake Eleanor | SJ | | 26 | M | P | San Francisco | 1918 |
| Lake Hodges | SC | | 34 | M | | San Diego City | 1918 |
| Lake Mathews | SC | 182 | | M, 3 | P | Western of Riverside MWD | 1918 |
| Woodward Res. | SJ | | 35 | I | PR | So. San Joaquin ID | 1918 |
| Gem Lake | SL | | 17 | | P | SCE | 1917 |
| Huntington Lake | SJ | | 89 | | P | SCE | 1917 |
| Pinecrest Lake (Main Strawberry) | SJ | | 18 | | PR | PG&E | 1916 |
| Turlock Lake | SJ | | 49 | I | PR | Turlock ID | 1915 |
| Clear Lake | SR | 313 | | IM | R | YCFCWCD | 1914 |
| Haiwee | SL | | 39 | M | PR | LADWP | 1913 |
| Lake Spaulding | SR | | 75 | | PR | PG&E | 1913 |
| Lake Tahoe | NL | 744 | | IM, 2 | AR | USBR | 1913 |
| Morena | SC | | 50 | M | | San Diego City | 1912 |
| Big Bear Lake (Bear Valley) | SC | | 73 | M | P | Bear Valley Mutual W.Co | 1911 |
| Modesto | SJ | | 29 | I | R | Modesto ID | 1911 |
| Bass Lake (Crane Valley) | SJ | | 45 | | P | PG&E | 1910 |
| Clear Lake | NC | 527 | | IM | PR, 2 | USBR | 1910 |
| East Park Res. | SR | | 51 | I | P | USBR | 1910 |
| Relief | SJ | | 15 | | P | PG&E | 1910 |
| South Lake (Hillside) | SL | | 13 | M | PR | SCE | 1910 |
| Tule Lake | SR | | 39 | I | R | Lyneta Ranches | 1904 |
| Lake Hemet | SC | | 11 | M | P | Lake Hemet MWD | 1895 |
| Dodge Res.(Red Rock #1) | SR | | 10 | I | | John Jay Casey | 1893 |
| Lake Chabot | SF | | 10 | M | | EBMUD | 1892 |
| McCoy Flat | NL | | 17 | I | | Lassen Irrig. Co. | 1891 |
| Crystal Springs (Lwr Crystal Sp) | SF | | 58 | M | | San Francisco | 1888 |
| Sweetwater | SC | | 28 | M | | South Bay ID(Sweetwt'r) | 1888 |
| Salt Springs Valley | SJ | | 10 | IM | | Rock Cr. W.D. | 1882 |
| San Andreas | SF | | 19 | M | | San Francisco | 1870 |
| French Lake | SR | | 14 | IM | PR | Nevada ID | 1859 |
| Total Storage (TAF) | | 35796 | 5562 | | | | |
| Total Number of Reservoirs | | 58 | 140 | | | | |

| Symbol | Project Uses & Special Notes |
|--------|--|
| F | Flood Control |
| I | Irrigation Water |
| M | Municipal &/or Industrial Water |
| P | Hydropower |
| A | Low Flow Augmentation or Fish Conservation |
| R | Recreation |
| D | Debris Dam |
| 2 | Interstate Water Used Jointly |
| 3 | Stores only Imported Colorado River Water |

* For Volumes of Reservoir Capacities for Years 1998, 2000 and 2001, Please refer to Volume 5.

Hydropower Projects Relicensing

The Federal Energy Regulatory Commission administers a program of licensing nonfederal hydroelectric power plants. FERC licenses establish conditions on the owners' operation of their plants; typical conditions include instream flow requirements and other fishery protection measures. Licenses for many California hydropower plants will be coming up for renewal in the near future. The relicensing process affords resource agencies and individuals the opportunity to seek changes in instream flow requirements, such as those suggested in CVPIA's draft AFRP. Hydropower generation is a nonconsumptive water use, but changes in the amount and timing of water diverted for power generation can affect other uses downstream. The impact of deregulation of the electric power industry on relicensing decisions is uncertain. Current owners of some generating facilities (especially smaller plants) may sell their generation assets in response to deregulation.

Water supply impacts of relicensing are difficult to quantify, in part because impacts are site-specific. Some plants subject to relicensing, for example, currently have no bypass flow requirements. It is likely that relicensing would establish bypass flows at these sites. Other plants subject to relicensing already have substantial bypass flows, and it is not clear what changes relicensing would bring.

CA. Hydropower Projects -License Years 2000 - 2010 (projects over 1,000 kW)

| License Expiration Date | Project | Stream | Licensee | Capacity (1,000 kW) |
|-------------------------|--------------------------------|---------------------------------|--|---------------------|
| June 2000 | Lower Tule | Middle Fork Tule River | Southern California Edison | 2.0 |
| September 2000 | Hat Creek No. 1 & 2 | Hat Creek & Pit River | Pacific Gas & Electric | 20.0 |
| February 2002 | El Dorado | South Fork American River | PG&E | 20.0 |
| April 2003 | San Geronio No. 1 & 2 | San Geronio Creek | SCE | 2.3 |
| August 2003 | Vermillion Valley | Mono Creek | SCE | N/A |
| September 2003 | Poe | North Fork Feather River | PG&E | 142.8 |
| October 2003 | Pit | Pit River | PG&E | 317.0 |
| April 2004 | Santa Felicia Reservoir | Piru Creek Santa Clara River | United Water Conservation District | 1.4 |
| October 2004 | Upper North Fork Feather River | North Fork Feather River | PG&E | 342.0 |
| December 2004 | Donnells & Beardsley | Middle Fork Stanislaus River | Oakdale & South San Joaquin Irrigation Districts | 64.0 |
| December 2004 | Tulloch | Stanislaus River | OID and SSJID | 17.1 |
| December 2004 | Stanislaus-Spring Gap | South Fork Stanislaus River | PG&E | 175.8 |
| February 2005 | Borel | Kern River | SCE | 9.2 |

| | | | | |
|---------------|----------------------|-------------------------------|--|-------|
| March 2005 | Portal | Rancheria Creek Big Creek | SCE | 10.0 |
| April 2005 | Kern Canyon | Kern River | PG&E | 11.5 |
| February 2006 | Klamath | Klamath River | Pacificorp | 231.0 |
| January 2007 | Feather River | Feather River | DWR | 844.0 |
| March 2007 | Kilarc & Cow Creek | Old Cow Creek & Cow Creek | PG&E | 8.9 |
| July 2007 | Upper American River | South Fork American River | SMUD | 722.3 |
| July 2007 | Chili Bar | South Fork American River | PG&E | 7.0 |
| November 2007 | Mammoth Pool | San Joaquin River | SCE | 181.0 |
| February 2009 | Big Creek No. 2A & 8 | South Fork San Joaquin River | SCE | 480.1 |
| February 2009 | Big Creek 3 | San Joaquin River | SCE | 177.5 |
| February 2009 | Big Creek No. 1 & 2 | Big Creek & San Joaquin River | SCE | 225.9 |
| March 2009 | South Fork | Kelly Ridge Canal | Oroville-Wyandotte Irrigation District | 104.1 |
| April 2009 | Santa Ana No. 3 | Santa Ana River | SCE | 1.5 |

Legislation

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Task Forces and Advisory Panels

Governor’s Advisory Drought Planning Panel’s Critical Water Shortage Contingency Plan

In response to the commitment in the CALFED Bay-Delta Program’s Record of Decision, the Governor convened a panel to develop a “contingency plan to reduce the impacts of critical water shortages primarily for agricultural and urban water users.” Panel members met four times between late August and December 2000 to hear informational briefings and to develop the contingency plan. The Panel recommended sixteen actions within broader categories:

- DWR should implement a Critical Water Shortage Reduction Marketing Program, building on experience gained from DWR’s past drought water banks. The program would be operated as a water purchasing and allocation program. DWR would acquire options to purchase water from willing sellers and would exercise the options as needed to make water available for sale to water users experiencing critical water shortages.
- DWR should provide technical assistance and educational programs to small water systems and homeowners in rural counties.
- DWR should establish an AB 3030 technical assistance program and update Bulletin 118 to provide improved groundwater data.
- DWR and other CALFED agencies should work in partnership with local water agencies to assist them in developing plans to facilitate integrated management of supplies for agricultural, urban, and environmental purposes.
- DWR should identify and seek funding for research in the areas of long-range weather forecasting, global climate change, and paleoclimatology. DWR should also develop regional hydrologic drought indices to help in statewide monitoring and develop a public outreach program to stress the need for drought preparedness.
- The Governor should take all possible actions to ensure rapid disbursement of Proposition 13 funds and that DWR maximize the use of rents, rather than capitalization loans, to bring local agencies up to the base level of water use efficiency contemplated in the CALFED ROD.

Floodplain Management

- Floodplain management includes actions to the floodplain to reduce losses to human resources within the floodplain and/or protect benefits to natural resources associated with flooding. For example:
- Minimizing impacts of flows
- Maintaining or restoring natural floodplain processes
- Removing obstacles within the floodplain voluntarily or with just compensation
- Keeping obstacles out of the floodplain
- Educating and emergency preparedness planning
- Ensuring that operations of floodwater management systems are not compromised by activities that interfere with, or are damaged by, design floods of these systems.

Stormwater Management Quality Task Force Recommendations

The California Stormwater Quality Task Force was formed in 1989 to assist the State Water Resources Control Board in implementing the NPDES Stormwater Program in California. Some of the task force work products include:

- Revision of California Best Management Practices Handbooks
- Input to regulatory initiatives on pesticides, permitting
- Public education and outreach
- Best management practice guidance

California Floodplain Management Task Force Recommendations

In an effort to reduce the impacts of flooding through better coordination of floodplain management, Assembly Bill 1147 recommended establishment of a Floodplain Task Force. The California Floodplain Management Task Force was established in early 2002 to examine specific issues related to State and local floodplain management. The Task Force, a diverse group of private, non-profit, and local interest groups and State, Federal, and local agencies, created over 30 recommendation for improved floodplain management. Recommendations then grew from three basic themes:

- Better Understanding and Reducing Risks from Reasonably Foreseeable Flooding. Local, State and federal agencies should consider the risk to life and property from reasonably foreseeable floods when making their land use and floodplain management decisions. To do this effectively, decision-makers need better tools and information and specific methods to comply with the federal National Flood Insurance Program (NFIP).
- Multi-Objective Management Approach for Floodplains – Multi-Objective Management Approach for Floodplains. State, local and federal agencies should implement multi-objective floodplain management on a watershed basis. Where feasible, projects should provide adequate protection for natural, recreational, residential, business, economic, agricultural, and cultural resources, and protect water quality and supply.
- Local Assistance, Funding, and Legislation for Floodplain Management. DWR should identify and actively pursue funding opportunities, technical assistance to local governments and other organizations, and legislative proposals to implement Task Force recommendations and ensure successful floodplain management, recognizing that local governments have the primary responsibility and authority for land use decisions.

The Reclamation Board of the State of California endorsed the California Floodplain Management Task Force Report on December 20, 2002. Floodplain use can influence water supply reliability including water quality.

Governor's Commission on Building for the 21st Century

Governor Davis convened a commission to consider the challenge of investing in the infrastructure of California for the 21st Century. The commission was directed to “study the building and infrastructure needs of California, with the intent of identifying existing critical infrastructure needs and developing a comprehensive long-term capital investment plan for financing public building needs, including responsible financial approaches and efficiency improvements.” The commission’s interim report in August 1999 outlined findings and recommendations for facilities, natural resources, technology and transportation. The commission recommended \$3 billion bond money for critical resources including water, parks, and open space.

State Recycling Task Force Recommendations

Assembly Bill 331 would require the Department of water resources to convene the 2002 Recycled Water Task Force with specified membership to advise the department in investigating the opportunities for using recycled water in industrial and commercial applications and in identifying impediments and constraints to increasing the industrial and commercial use of recycled water, and would require a report to the Legislature with recommendations on specified topics not later than July 1, 2003.

Joint Task Force on California Watershed Management Recommendations

- Adopt a Statewide Watershed Policy
- Develop a Strategic Plan
- Improve Technical Assistance & Communication
- Clarify Link to Regulations
- Leverage Multiple funding Sources and Consider Long-Term Funding
- Ensure Watershed Partnerships have Access to Science and Monitoring
- Ensure Public Accountability

The Task Force identified and adopted 26 issues with respective recommendations to address obstacles, impediments, and opportunities for California to increase its recycled water usage. Among the key findings, possibilities of enhanced use of recycled water in landscape irrigation of highway medians, golf courses, parks, and schoolyards; industrial uses such as power station cooling towers, oil refinery boiler feed water, carpet dyeing, recycled newspaper processing, laundries; and agricultural uses such as irrigation of produce, pastures for animal feed, and nursery plant products and in office buildings for toilet flushing would lead to save fresh water. The task force concluded that California has the potential to recycle up to 1.5 million acre-feet per year of water by the year 2030. This could free up freshwater supplies to meet approximately 30 percent of the household water needs associated with projected population growth. However, to achieve that potential, Californians will have to invest nearly \$11 billion (approximately \$400 million annually) for additional infrastructure to produce and deliver the recycled water.

State Watershed Management Guidelines and Initiative

Assembly Bill 2117 (Wayne, Chapter 735, Statutes of 2000) required a report to the Legislature on California's watershed status and any needed changes in State laws. The State Secretary for Resources and Chair of the State Water Resources Control Board formed the Joint Task Force on California Watershed Management, an interagency and stakeholder effort, to discuss the results of the ten case studies, to refine the findings, and to craft major recommendations to move the State in a new direction to protect and restore watersheds, lakes, rivers and estuaries in California. The Task Force's April 2002 report, Addressing the Need to Protect California's Watersheds: Working with Local Partnerships, contained six major recommendations.

Water Desalination Task Force

This Assembly Bill would require the Department of Water Resources, not later than July 1, 2004, to report to the Legislature, on potential opportunities and impediments for using seawater and brackish water desalination, and to examine what role, if any, the state should play in furthering the use of desalination technology. The bill would require the department to convene a Water Desalination Task

Force, comprised of representatives from listed agencies and interest groups, to advise the department in carrying out these duties and in making recommendations to the Legislature.

The Task force came up with 41 key findings and 29 major recommendations. Among these it was identified that desalination can provide significant value and numerous benefits. These include:

- Providing additional water supply to meet existing and projected demands
- Replacing water lost from other sources and relieving drought conditions
- Enhancing water reliability and supplying high quality potable water
- Reducing groundwater overdraft and restoring use of polluted groundwater
- Replacing water that can be used for river and stream ecosystem restoration

Recent Water Legislation

Legislative changes and programmatic actions within the last five years have provided new definition for planning for improved water supply reliability. In addition to the Water Bonds mentioned earlier, new legislation has focused on local water planning.

Improve Water Management and Integrated Planning

The California Legislature has produced several regulations to improve water management and integrated planning at the local level.

- ***SB 1075 (Johnston, Chapter 583, Statutes of 1998) – Delta Protection Commission.*** Senate Bill 1075 extends the Delta Protection Commission to January 1, 2010, and authorizes the commission to facilitate the implementation of any joint habitat-restoration programs within the primary zone of the Delta.
- ***SB 1765 (Peace, Chapter 813, Statutes of 1998) – Colorado River Management Program.*** Senate Bill 1765 appropriates funds to DWR for implementation of the California 4.4 Plan developed by the Colorado River Board and to the Salton Sea Authority for a study. The majority of the funds are for canal lining the All American Canal and the Coachella Branch of the All American Canal.
- ***SB 496 (Sher, Chapter 1016, Statutes of 1999) – Wild and Scenic Rivers: South Yuba River.*** Senate Bill 496 adds the South Yuba River to the State’s wild and scenic rivers system. AB 1593 is the companion bill, which delays designation of the South Yuba River for 1 year.
- ***SB 970 (Costa, Chapter 938, Statutes of 1999) – Water Rights.*** Senate Bill 970 enacts the Water Rights Protection and Expedited Short-term Water Transfer Act of 1999 to streamline the administrative process for approval or denial of water transfers by the State Water Resources Control Board and requires general public notice of water transfers.
- ***SB 1062 (Poochigian, Chapter 210, Statutes of 1999) – The California Water Plan.*** Senate Bill 1062 requires DWR to include various strategies for meeting the state’s water supply needs in its updates to the California Water Plan. The update must identify all federal and state permits, approvals or entitlements that might be required in order to implement the strategies. It also establishes an advisory committee to help DWR update the plan.
- ***AB 1593 (Villaragiosa, Chapter 1017, Statutes of 1999) – Wild and Scenic Rivers: South Yuba River.*** Assembly Bill 1593 designates the South Yuba River as “wild and scenic” to be effective January 1, 2001. This is the companion bill to SB 496.
- ***AB 1147 (Honda, Chapter 1071, Statutes of 2000) – Flood Control.*** Assembly Bill 1147 establishes legislative intent for the Governor to establish a Floodplain Management Task force, provides for greater State oversight of flood control projects, changes the nonfederal cost share equation for flood control projects, and authorizes several flood control projects.

- ***SB 1341 (Burton, Chapter 720, Statutes of 2000) - State Water Plan.*** Senate Bill 1341 requires DWR to release a preliminary Draft of the *California Water Plan's* water assumptions and estimates and restructures Water Code Section 10004 relevant to the *California Water Plan*.
- ***SB 221 (Keuhl, Chapter 642, Statutes of 2001) - Certification of Sufficient Water Supply.*** Senate Bill 221 requires local agencies to provide written verification that sufficient water supply is available before approving plans for new development.
- ***SB 610 (Costa, Chapter 643, Statutes of 2001) - Water Supply Planning.*** Senate Bill 610 requires additional information be included as part of an urban water management plan if groundwater is identified as a source of water available to the supplier. It requires an urban water supplier to include in the plan, a description of all water supply projects and programs that may be undertaken to meet total projected water use. In response to SB 221 and SB 610, DWR prepared *The State Water Project Delivery Reliability Report* to assist the SWP contractors in assessment of the adequacy of the SWP component of their overall water supplies. In the near future, DWR will be publishing a guidebook on how cities and counties can comply with Senate Bills 221 and 610.
- ***SB 672 (Machado, Chapter 320, Statutes of 2001) - Regional Planning & Water Plan Update.*** Senate Bill 672 requires the State to include in the California Water Plan, a report on the development of regional and local water projects, within each hydrologic region to improve water supplies to meet municipal, agricultural, and environmental water needs and minimize the need to import water from other hydrologic regions. This bill also requires urban water suppliers to describe in their urban water management plans, water management tools and options used by that entity that will maximize resources and minimize the need to import water from other regions.
- ***SB 482 (Kuehl, Chapter 617, Statutes of 2002).*** Senate Bill 482 was passed to help clear the way for the Colorado River Water Use Plan. Since the Plan could negatively impact some Salton Sea species, SB 482 permits the killing of certain fully protected species found in the Salton Sea.
- ***AB 857 (Wiggins, Chapter 1016, Statutes of 2002) - State Strategic Planning.*** Assembly Bill 857 establishes three specific planning priorities for the State:
 1. To promote infill development and equity by rehabilitating, maintaining, and improving existing infrastructure that supports infill development and appropriate reuse and redevelopment of previously developed, underutilized land that is presently served by transit, streets, water, sewer, and other essential services, particularly in underserved areas, and to preserving cultural and historic resources.
 2. To protect environmental and agricultural resources by protecting, preserving, and enhancing the state's most valuable natural resources, including working landscapes such as farm, range, and forest lands, natural lands such as wetlands, watersheds, wildlife habitats, and other wildlands, recreation lands such as parks, trails, greenbelts, and other open space, and landscapes with locally unique features and areas identified by the state as deserving special protection.
 3. To encourage efficient development patterns by ensuring that any infrastructure associated with development that is not infill supports new development that uses land efficiently, is built adjacent to existing developed areas to the extent consistent with the priorities specified pursuant

to subdivision (b), is in an area appropriately planned for growth, is served by adequate transportation and other essential utilities and services, and minimizes ongoing costs to taxpayers.

- ***SB 1938 (Machado, Chapter 603, Statutes of 2002) - Groundwater Management Plans.*** Senate Bill 1938 requires a local agency, in order to qualify for state funds, to prepare and implement or consent to be subject to a groundwater management plan, a basinwide management plan, or other integrated regional water management program or plan that addresses five specific groundwater management components described in the bill. SB 1938 amended Water Code section 10750 et seq.
- ***SB 1653 (Costa, Chapter 812, Statutes of 2002) – California Bay-Delta Act.*** Senate Bill 1653 creates the California Bay-Delta Authority. The Authority will sunset on January 1, 2006, unless federal legislation has been enacted authorizing the participation of appropriate federal agencies in the Authority.
- ***SB 1672 (Costa, Chapter 767, Statutes of 2002) - Integrated Regional Water Management Planning.*** Senate Bill 1672 authorizes local public agencies to form regional water management groups and adopt regional plans to address “qualified programs or projects.” This bill requires DWR and other departments to give preference to “qualified programs or projects” when establishing criteria for funding under various programs.
- ***AB 2534 (Pavley, Chapter 727, Statutes of 2002) – Watershed, Clean Beaches, and Water Quality.*** Assembly Bill 2534 provides \$175 million in Proposition 40 funding as grants to public agencies and nonprofit organizations for projects designed to improve water quality at public beaches, improve water quality monitoring and sewer capability, reduce storm water runoff pollution, improve agricultural water quality and develop and implement local watershed management projects.
- ***AB 2587 (Matthews, Chapter 615, Statutes of 2002) – Food: Water Usage Forecasts.*** Assembly Bill 2587 requires the Department of Food and Agriculture to estimate food, fiber, livestock, and other farm products production and provide that information to the Department of Water Resources for estimating related water usage reported in Bulletin 160. The bill also states the intent of the Legislature that the food forecasts include the following considerations:
 1. Neither the state nor the nation should be allowed to become dependent upon a net import of foreign food.
 2. As the nation’s population grows, California should produce enough food to supply the state and also continue to supply the historical proportion of the nation’s food supply, approximately 25 percent of the nation’s table food.
 3. Countries such as Japan are heavily dependent on imported food, some of which comes from California. California is also called upon to ship food to prevent famines and to protect our national interest by providing food to maintain stability elsewhere in the world. Consideration should be given to maintaining the state’s ability to meet these export needs.

Recycling, Desalination and Groundwater Potential for Increasing Supplies

- ***AB 303 (Thomson, Chapter 708, Statutes of 2000) – Groundwater.*** Assembly Bill 303 enacts the Local Groundwater Management Assistance Act of 2000 to establish a grant program within DWR to provide funding to local public agencies to implement groundwater monitoring and management activities.
- ***AB 331 (Goldberg, Chapter 590, Statutes of 2001) - 2002 Recycled Water Task Force.*** Assembly Bill 331 AB 331 requires DWR to report to the Legislature by July 1, 2003, on opportunities for increasing the use of recycled water in industrial and commercial applications and identify the constraints and impediments to increasing such use. The bill requires DWR to convene the Recycled Water Task Force with specified members who would advise the Department on preparing the report. The bill requires the DWR to carry out the provisions only to the extent that funds from the Safe Drinking Water, Clean Water, Watershed Protection and Flood Protection Act (Proposition 13) are made available by the State Water Resources Control Board.
- ***AB 599 (Liu, Chapter 522, Statutes of 2001)—The Groundwater Quality Monitoring Act of 2001.*** Assembly Bill 599 requires the State Water Resources Control Board to integrate existing monitoring programs and design new program elements for the purpose of establishing a comprehensive groundwater quality monitoring program to assess all groundwater basins in the State. This bill requires SWRCB to create an interagency task force to assist SWRCB in designing the monitoring program and requires SWRCB to convene an advisory committee to assist the interagency group. This bill requires a multiagency report to the Governor and the Legislature by January 1, 2002, on the status of implementation of the new law.
- ***SB 1191 (Speier, Chapter 745, Statutes of 2001) –State and Local Reporting Requirements.*** Senate Bill 1191 eliminates specific legislatively mandated reports, which are prepared by the Department.
- ***SB 1518 (Torlakson, Chapter 261, Statutes of 2002) – Recycled Water.*** Senate Bill 1518 allows sanitation districts, after proper notification, to provide recycled water within the boundaries of a city, water district or other local agency that also provides similar water service. This bill requires that specific information about the use of recycled water be added to urban water management plans.
- ***AB 2717 (Hertzberg, Chapter 957, Statutes of 2002) – State Desalination Task Force.*** Assembly Bill 2717 requires DWR, not later than July 1, 2004, to report to the Legislature on potential opportunities and impediments for using seawater and brackish water desalination, and to examine what role, if any, the state should play in furthering the use of desalination technology. Rather than accepting the \$600,000 appropriation in the bill, Governor Davis reduced the appropriation to \$100,000 and directed DWR to explore funding partnerships with interested local and private entities to accomplish the study

Water Allocation, Use and Regulation in California

In California, water use and supplies are controlled and managed under an intricate system of common law principles, constitutional provisions, State and federal statutes, court decisions, and contracts or agreements. All of these components constitute the institutional framework for the protection of public interests and their balance with private claims in California's water allocation and management.

Constitutional, Statutory and Common Law Framework for Water Uses

The people of California own all the water in the State. Water rights provide the right to reasonable and beneficial use of the water, not ownership of the water. Public interests are thus involved at every level of water management in California.

Principle of Reasonable and Beneficial Use

California's water law and policy, Article X, Section 2 of the California Constitution, requires that all uses of the State's water be both reasonable and beneficial. It places a significant limitation on water rights by prohibiting the waste, unreasonable use, unreasonable method of use, or unreasonable method of diversion of water. However, the interpretation of what is wasteful can vary significantly depending on the circumstances and may depend on opinions of the SWRCB or ultimately, the courts.

Public Trust Doctrine Values and Trustees

Rights to use water are subject to the State's obligation under the Public Trust Doctrine as trustee of certain resources for Californians. The Public Trust Doctrine is a legal doctrine that imposes responsibilities on State agencies to protect trust resources associated with California's waterways, such as navigation, fisheries, recreation, ecological preservation and related beneficial uses. In *National Audubon Society v. Superior Court of Alpine County*, the California Supreme Court concluded that the public trust is an affirmation of the duty of the State to protect the people's common heritage of streams, lakes, marshlands, and tidelands, surrendering such protection only in rare cases when the abandonment of that right is consistent with the purposes of the trust. Thus, California agencies have fiduciary obligations to the public when they make decisions affecting trust assets.

CALIFORNIA CONSTITUTION ARTICLE 10 WATER

SEC. 2. It is hereby declared that because of the conditions prevailing in this State the general welfare requires that the water resources of the State be put to beneficial use to the fullest extent of which they are capable, and that the waste or unreasonable use or unreasonable method of use of water be prevented, and that the conservation of such waters is to be exercised with a view to the reasonable and beneficial use thereof in the interest of the people and for the public welfare. The right to water or to the use or flow of water in or from any natural stream or water course in this State is and shall be limited to such water as shall be reasonably required for the beneficial use to be served, and such right does not and shall not extend to the waste or unreasonable use or unreasonable method of use or unreasonable method of diversion of water. Riparian rights in a stream or water course attach to, but to no more than so much of the flow thereof as may be required or used consistently with this section, for the purposes for which such lands are, or may be made adaptable, in view of such reasonable and beneficial uses; provided, however, that nothing herein contained shall be construed as depriving any riparian owner of the reasonable use of water of the stream to which the owner's land is riparian under reasonable methods of diversion and use, or as depriving any appropriator of water to which the appropriator is lawfully entitled. This section shall be self-executing, and the Legislature may also enact laws in the furtherance of the policy in this section contained.

In National Audubon, the court addressed the relationship between the Public Trust Doctrine and California's water rights system, and integrated them. The Court reached three major conclusions:

- The State retains continuing supervisory control over its navigable waters and the lands beneath them. This prevents any party from acquiring a vested right to appropriate water in a manner harmful to the uses protected by the public trust. The State Water Resources Control Board may reconsider past water allocation decisions in light of current knowledge and current needs.
- As a practical matter, it will be necessary for the State to grant usufructuary licenses to allow appropriation of water for uses outside the stream, even though this taking may unavoidably harm the trust uses of the source stream.
- "The State has an affirmative duty to take the public trust into account in the planning and allocation of water resources, and to protect public trust uses whenever feasible."

Thus, while the State may, as a matter of practical necessity, have to approve appropriations that will cause harm to trust uses, it "must at all times bear in mind its duty as trustee to consider the effect of such taking on the public trust, (cite omitted) and to preserve, so far as consistent with the public interest, the uses protected by the trust."

Surface Water Rights

California's system for surface water rights recognizes both riparian rights and appropriative rights. Riparian rights were adopted in California as a part of the English Common Law when California became a state in 1850. At that time, gold miners were already operating under their own system that recognized claims to water rights based on prior appropriation.

Riparian

A riparian right is the right to divert, but not store, a portion of the natural flow for use based on the ownership of property adjacent to a natural watercourse. Water claimed through a riparian right must be used on the riparian parcel. Such a right is generally attached to the riparian parcel of land except where a riparian right has been preserved for non-contiguous parcels when land is subdivided. Generally, riparian rights are not lost through non-use. All riparian water users have the same priority; senior and junior riparian water rights do not exist. During times of water shortage, all riparian water users must adjust their water use to allow equal sharing of the available water supply.

Appropriative

Under the prior appropriation doctrine, a person may acquire a right to divert, store, and use water regardless of whether the land on which it is used is adjacent to a stream or within its watershed. The rule of priority between appropriators is "first in time is first in right." A senior appropriative water rights holder may not change an established use of the water to the detriment of a junior, including a junior's reliance on a senior's return flow. Acquisition of appropriative water rights is subject to the issuance of a permit by the State Water Resources Control Board (SWRCB) with priority based on the date a permit is issued. Permit and license provisions do not apply to pre-1914 appropriative rights (those initiated before the Water Commission Act took effect in 1914), but pre-1914 rights are still subject to reasonable and beneficial use. Appropriative rights may be sold or transferred.

Groundwater Use and Management

With the exception of the 19 adjudicated groundwater basins and basins in which a local agency has obtained statutory authority to manage groundwater, any overlying landowner in California has the right to build a well and extract groundwater as long as that groundwater is put to a reasonable and beneficial use. In 1903, the California Supreme Court rejected the English Common Law system of absolute

ownership of groundwater, which allowed for unregulated pumping of groundwater. Instead, the court adopted the rule of "reasonable use of percolating waters." This established the doctrine of "correlative rights and reasonable use" under which every landowner in the basin has a right to extract and use groundwater and that right is correlative with the rights of all the overlying landowners in the basin. Those correlative rights are not quantified until the basin is adjudicated. An overlying landowner's right is considered to be analogous to a riparian right to surface water. Groundwater can be appropriated by taking the water for use on non-overlying lands if water is surplus to the reasonable needs of overlying owners.

California does not have a statewide management program or permit system to regulate the extraction and appropriation of groundwater. Courts have recognized that groundwater management is the responsibility of local agencies. In addition to the 19 adjudicated basins in which groundwater extraction is regulated by the watermaster appointed by State or federal courts, some local agencies have obtained statutory authority from the legislature to manage groundwater within their agency's boundaries. Statutory management may be granted to a public agency that also manages surface water, or to a groundwater management agency created expressly for that purpose by a special district act. There are 9 such special districts, but most have not successfully developed groundwater management plans. Several other local agencies have obtained statutory authority to manage groundwater by returning to the legislature and requesting amendments to the Water Code to allow them to manage groundwater. Only a few of these agencies have enacted a groundwater replenishment fee, a groundwater extraction fee, or a recharge fee, all of which are colloquially called a "pump tax." Water resources are specifically referenced in general plan statutes and mandate close coordination of land use and water supply agencies. More recently, some counties have enacted ordinances that are aimed primarily at protecting groundwater resources within their county.

In 1991, the Water Code was amended by AB 255 to allow local water agencies overlying critically overdrafted groundwater basins to develop groundwater management plans. Seven local agencies adopted plans pursuant to that authorization. In 1992, the Water Code was again amended by AB 3030, which authorized water agencies in any groundwater basin to develop a groundwater management plan, if the groundwater was not subject to management under other provisions of law or a court decree. Plans adopted pursuant to the 1992 statute may include, but are not limited to, 12 technical components including control of salt water intrusion; identification and protection of wellhead and recharge areas; regulation of the migration of contaminated water; provisions for abandonment and destruction of wells; mitigation of overdraft; replenishment; monitoring; facilitating conjunctive use; identification of well construction policies; and construction of cleanup, recharge, recycling, and extraction projects by the local agency. About 190 agencies have adopted groundwater management plans in accordance with AB 3030.

The same part of the Water Code (section 10750 et seq.) was amended again in 2002 by SB 1938 and now requires that 5 specific components must be included in a groundwater management plan if the agency applies for State funding made available after September 1, 2002. Even if an agency does not apply for State funding, however, the legislature's intent was to provide standards for groundwater management by prudent groundwater managers. Applicant agencies for funding authorized by AB 303 (Thomson, Chapter 708, Statutes of 2000) are specifically excluded from the required components in that such funding was intended by the legislature to enable under funded local agencies to begin a

groundwater management program. Again, however, a prudent manager would strive to meet minimum standards.

Tribal Water Rights

Some Indian reservations and other federal lands have reserved water rights implied from acts of the federal government, rather than state law. When tribal lands were reserved, their natural resources were also reserved for tribal use. Since reserved tribal rights were generally not created by state law, states' water allocations did not account for tribal resources. In the landmark *Winters v. U.S.* case, in 1908 the U.S. Supreme court established that sufficient water was reserved to fulfill the uses of a reservation at the time the reservation was established. The decision, however, did not indicate a method for quantifying tribal water rights. Winters rights also retain their validity and seniority over state appropriated water whether or not the tribes have put the water to beneficial use. Only after many years did tribes begin to assert and develop their reserved water rights. In 1963 the U.S. Supreme Court decision *Arizona v. California* reaffirmed Winters and established a quantification standard based on irrigation, presupposing that tribes would pursue agriculture. Despite criticisms of the "practicably irrigable acreage" (PIA) quantification standard from various perspectives, the PIA standard provided certainty to future water development. Quantifying water needs in terms of agricultural potential does not accurately show the many other needs for water. Even urban water quantity and quality assessments that look at the adequacy of the domestic water supply and sanitation do not provide a complete picture of tribal water needs. A large part of the tribal water needs are for instream flows and other water bodies that support environmental and cultural needs for fishing, hunting, and trapping.

The 1902 Reclamation Act promulgated the establishment of irrigated agriculture and settlement throughout the Western states. Historical perspective indicates this policy was pursued generally without regard to Indian water rights or the 1908 Winters decision. In 1952 Congress passed the McCarran Amendment allowing the federal government to waive sovereign immunity and participate in state general stream adjudications. The Court later ruled that state adjudications may also apply to Indian reserved water rights held in trust by the United States. In asserting their Winters rights, tribes have come into conflict with water-using development that grew out of substantial federal and private investment. Costly litigation, negotiation, or combinations thereof are the usual means of resolving Indian water disputes, and some cases can take decades to reach agreement. Some tribes request assistance from the federal government to pursue their water rights settlements, reminding concerned parties of the conflicting roles the federal government can assume on two or more sides of a judicial or administrative issue.

The Law of the River

The Colorado River is managed and operated under numerous compacts, federal laws, court decisions and decrees, contracts, and regulatory guidelines collectively known as the "Law of the River." In 1922, the seven Colorado River basin states negotiated the Colorado River Compact, which divided the states into two basins—upper and lower—and apportioned 7.5 million acre-feet per year to each basin. The compact also referenced Mexico's right to the Colorado. The Boulder Canyon Project Act of 1928 ratified the Compact and established California's apportionment at 4.4 maf/year. In 1944, the United States signed a water treaty in which it agreed to deliver an annual quantity of 1.5 million acre-feet of water annually to Mexico.

While compact negotiators estimated the flow of the river to be at least 17 million acre-feet per year, today's records indicate a flow of 15 million at Lee Ferry, just below Lake Powell. Consequently, the sum of the actual compact apportionments and the Mexican treaty exceed the flow of the river in most years.

Water Contracts

Both the SWP and CVP have contracts to deliver water to water agencies:

State Water Project

DWR has long-term water supply contracts for water service from the State Water Project with 29 local agencies from Plumas County Flood Control and Water Conservation District in the north to the Metropolitan Water District of Southern California in the south. In return for State financing, constructing, operating, and maintaining facilities needed to provide water service, the agencies contractually agreed to repay all associated SWP capital and operating costs. The Annual Table A represents the total amount of project water that a SWP contractor may request each year, according to that contractor's long-term water supply contract. Depending on hydrologic conditions, the actual delivery may be different than the requested amount. The majority of the SWP goes to urban uses. As a result of amendments to contracts in the 1990s, the current combined maximum annual Table A amount totals 4,172,786 acre-feet for all 29 contractors. The contracts are in effect for the longest of the following periods: (1) the project repayment period, which extends to the year 2035; (2) 75 years from the date of the contract; or (3) the period ending with the latest maturity date of any bond used to finance the construction costs of project facilities.

Central Valley Project

The CVP supplies water to more than 250 long-term water contractors extending from Shasta County in the north to Kern County in the south. The majority of the CVP water goes to agricultural uses. Collectively, the contracts call for a maximum annual delivery of 9.3 MAF; 4.8 MAF is classified as project water and 4.5 MAF is classified as water right settlement water. Contractors that receive project water repay project capital and operation and maintenance costs. Water right settlement water is water covered in agreements with water rights holders whose diversions existed before the project was constructed. Project operations altered natural river flow upon which these pre-project diverters had relied, so contracts were negotiated to agree on the quantities of diversions that could be made without any payment to the United States. Water rights settlement contractors on the upper Sacramento River receive their supply from natural flow and storage regulated at Shasta Dam. Settlement contractors on the San Joaquin River (called exchange contractors) receive Delta water diverted from the Delta and stored in San Luis Reservoir and/or pumped directly via the Delta-Mendota Canal.

Releases of Water for Environmental Uses

Fish and Game Code Section 5937 provides protection to fisheries by requiring that the owner of any dam allow sufficient water to pass downstream to keep in good condition any fisheries that may be planted or exist below the dam. See the adjoining page for other resource management regulations. See the adjoining page for other environmental regulations.

Water Transfers

Every year, hundreds of water transfers take place between water users within water districts. These districts have their own rules for the initial allocation of water to their users. Water transfers between water districts within the same water basin are becoming more common. Local rules allow districts to transfer water through groundwater banking agreements or other joint water development projects. In

many cases, local rules provide members the right of first refusal to obtain the water before the water is transferred to outside parties. Emergency water transfers are generally exempt from CEQA review.

In 1995 and 1996, the SWP negotiated a set of principles (Monterey Agreement), which among other things, changed the operating rules of the SWP to allow banking and limited water transfers among SWP users. Based on these principles and a final EIR, twenty-seven of the 29 SWP contractors executed the amendment (Monterey Amendment) to their contracts. Based on challenges to the EIR, DWR is preparing a new EIR for the Monterey Amendment.

CVPIA authorized transfer of project water outside the CVP service area, subject to many conditions, including a right of first refusal by entities within the service area. Transfers must be consistent with State law, be approved by USBR, and be approved by the contracting water district if the transfer involves more than 20 percent of its long-term contract supply. USBR has published interim guidelines for administration of this provision, pending formal promulgation of rules and regulations.

In the mid-1980s and 1990s, the Legislature passed several laws making it easier to transfer water beyond the boundaries of historical water service areas. These laws are aimed at protecting water users who are not a party to the transfer and fish and wildlife from being injured or unreasonably affected by the transfer. These laws developed an expedited process for the SWRCB to expand the water rights of those conducting a short-term (one year) water transfer. The process requires SWRCB to make findings within 45 days. Once the findings are made, the water right is modified to allow the water right holder to serve, on a temporary basis, additional places of use or to use alternative points of diversion. The receiving party gets the use of the water, but does not obtain any rights to the water; the water rights are maintained by the original water right holder.

CALFED included actions to facilitate water transfers. The ON TAP website provides information and disclosure of water market information resources for water users. (See <http://ontap.ca.gov>).

DWR purchases water for the newly created Environmental Water Account and the Dry Year Program for California. DWR has made it clear in recent water transfer papers that it only will be involved in the purchase of water from willing sellers who include in their proposals monitoring and mitigation programs that resolve possible impacts to other water users and fish and wildlife; see www.watertransfers.water.ca.gov. DWR has evaluated its role as a water purchaser in light of the legislative guidance provided in the Water Code regarding water transfers. Through this evaluation DWR has defined the nature of the water it wishes to purchase in much the same way that any consumer in the marketplace decides the nature of the products to be purchased. These definitions are seen as a step toward creating a more equitable water market that addresses early in the process the impacts to third parties. These same issues and the development of mechanisms to resolve them are part of a settlement process between northern California water users, the CVP, and the SWP regarding the role northern California should play in making water available to assist in meeting water quality standards in the Delta.

Area of Origin Protections

During the years when California's two largest water projects, the CVP and SWP, were being planned and developed, area of origin provisions were added to the water code to protect local Northern California supplies from being depleted by the projects. County of origin statutes reserve water supplies for counties in which the water originates when, in the judgment of the SWRCB, an application for the assignment or

release from priority of State water right filings will deprive the county of water necessary for its present and future development. Watershed protection statutes are provisions that require that the CVP and the SWP not deprive those in a watershed from the future beneficial water needs.

The Delta Protection Act, enacted in 1959 (not to be confused with the Delta Protection Act of 1992), declares that the maintenance of an adequate water supply in the Delta to maintain and expand agriculture, industry, urban, and recreational development in the Delta area and provide a common source of fresh water for export to areas of water deficiency is necessary for the peace, health, safety, and welfare of the people of the State, and is subject to the County of Origin and Watershed Protection laws. The act requires the SWP and the CVP to provide salinity control in the Delta and an adequate water supply for water users in the Delta.

In 1984, additional area of origin protections were enacted covering the Sacramento, Mokelumne, Calaveras, and San Joaquin Rivers; the combined Truckee, Carson, and Walker Rivers; and Mono Lake. The protections prohibit the export of groundwater from the combined Sacramento River and Delta Basins, unless the export is in compliance with local groundwater plans.

Regulations Protecting Water Quality

Water quality is an important aspect of water resource management. Discussed below are the key State and federal laws governing water quality.

Clean Water Act-National Pollutant Discharge Elimination System

Section 402 of the Clean Water Act established a permit system known as the National Pollutant Discharge Elimination System (NPDES) to regulate point sources of discharges in navigable waters of the United States. The EPA was given the authority to implement the NPDES, although the Act also authorizes states to implement the NPDES program in lieu of the EPA, provided the state has sufficient authority.

After the Clean Water Act was enacted in 1972, US EPA and the states focused primarily on implementing technology-based controls for “point” sources (for example, discharges from pipes from factories and municipal sewage treatment plants). Today, those controls are largely in place, and the focus is beginning to shift to “non-point source” pollution, such as runoff from cities and farms.

Porter-Cologne Water Quality Control Act

This Act is California's comprehensive water quality control law and is a complete regulatory program designed to protect water quality and beneficial uses of the State's water.

The Act requires the adoption of water quality control plans by the State's nine RWQCBs for watersheds within their regions. These plans are nominally reviewed and updated triennially, and their adoption is subject to the approval of the SWRCB and ultimately the federal EPA. Moreover, pursuant to Porter-Cologne, these basin plans shall become part of the California Water Plan, when such plans have been reported to the Legislature (Section 13141, California Water Code).

In 1972, the Legislature amended the Porter-Cologne Act to give California the authority and ability to operate the federal NPDES permits program. Before a permit may be issued, Section 401 of the Clean

Water Act requires that the RWQCB certify that the discharge will comply with applicable water quality standards. In addition, under Porter-Cologne, the RWQCB may also issue waste discharge requirements, that set conditions on the discharge of a waste. These requirements must be consistent with the water quality control plan for the body of water that receives the waste discharge, as well as protect the beneficial uses of those receiving waters.

The regional boards also implement Section 402 of the federal Clean Water Act, which allows the State to issue a single discharge permit for stormwater runoff for the purposes of both State and federal law.

Safe Drinking Water Act

The Safe Drinking Water Act (SDWA), enacted in 1974 and significantly amended in 1986 and 1996, directed the EPA to set national standards for drinking water quality. It required the EPA to set maximum contaminant levels for a wide variety of constituents. Local water suppliers are required to monitor their water supplies to assure that regulatory standards are not exceeded.

The Maximum Contaminant Level (MCL) is the maximum concentration of a contaminant that is allowed in public drinking water systems. The 1986 amendments set a timetable for the EPA to establish standards for specific contaminants and increased the range of contaminants local water suppliers were required to monitor to include contaminants that did not yet have an MCL established. The 1986 Safe Drinking Water Act Amendments also led to the EPA's adoption of the Surface Water Treatment Rule, which addresses filtration and disinfection of surface waters. The amendments included a wellhead protection program, a grant program for designating sole-source aquifers for special protection, and grant programs and technical and financial assistance to small systems and states.

The 1996 amendments included stronger regulation of microbial contaminants (i.e. Cryptosporidium) while managing levels of disinfection byproducts, source water assessment programs, and establishment of a drinking water state revolving fund. The source water assessment and protection programs offer tools and opportunities to build a prevention barrier to drinking water contamination. Under SDWA, the state is required to develop comprehensive Source Water Assessment Programs that will identify the areas that supply public tap water, inventory contaminants and assess water system susceptibility to contamination, and inform the public of the results.

For every new standard, EPA conducts an analysis to determine if the benefits of the standard justify the costs. If not, EPA may adjust the MCL to a level that “maximizes the health risk reduction benefits at a cost that is justified by the benefits.”

California Safe Drinking Water Act

In 1976, California enacted its own Safe Drinking Water Act, requiring DHS to regulate drinking water, including: setting and enforcing federal and State drinking water standards; administering water quality testing programs; and administering permits for public water system operations. In 1989, significant amendments to the California act incorporated the new federal safe drinking water act requirements into California law, gave DHS discretion to set more stringent MCLs, and recommended public health levels for contaminants.

Environmental Laws for Protecting Resources

Several laws outline the State and federal obligations to protect and restore degraded habitats and species.

Protecting Endangered Species and Habitats

Federal Endangered Species Act

Under the federal ESA, an endangered species is one that is in danger of extinction in all or a significant part of its range, and a threatened species is one that is likely to become endangered in the near future. The ESA is designed to preserve endangered and threatened species by protecting individuals of the species and their habitat and by implementing measures that promote their recovery. The ESA sets forth a procedure for listing species as threatened or endangered. Final listing decisions are made by USFWS or NMFS.

Once a species is listed, Section 7 of the act requires that federal agencies, in consultation with the USFWS or NMFS, ensure that their actions do not jeopardize the continued existence of the species or habitat critical for the survival of that species. The federal wildlife agencies are required to provide an opinion as to whether the federal action would jeopardize the species. The opinion must include reasonable and prudent alternatives to the action that would avoid jeopardizing the species' existence. Federal actions subject to Section 7 include issuance of federal permits such as the dredge and fill permit required under Section 404 of the federal Clean Water Act, which requires that the project proponent demonstrate that there is no feasible alternative consistent with the project goals that would not affect listed species. Mitigation of the proposed project is not considered until this hurdle is passed.

State agencies and private parties also are subject to the ESA. Section 9 of the ESA prohibits the "take" of endangered species and threatened species for which protective regulations have been adopted. Take has been broadly defined to include actions that harm or harass listed species or that cause a significant loss of their habitat. State agencies and private parties are generally required to obtain a permit from the USFWS or NMFS under Section 10(a) of the ESA before carrying out activities that may incidentally result in taking listed species. The permit normally contains conditions to avoid taking listed species and to compensate for habitat adversely impacted by the activities.

California Endangered Species Act

The California Endangered Species Act is similar to the federal ESA. Listing decisions are made by the California Fish and Game Commission. All State lead agencies are required to consult with the Department of Fish and Game about projects that impact State listed species. DFG is required to render an opinion as to whether the proposed project jeopardizes a listed species and to offer alternatives to avoid jeopardy. State agencies must adopt reasonable alternatives unless there are overriding social or economic conditions that make such alternatives infeasible. For projects causing incidental take, DFG is required to specify reasonable and prudent measures to minimize take. Any take that results from activities that are carried out in compliance with these measures is not prohibited.

Many California species are both federally listed and State listed. CESA directs DFG to coordinate with the USFWS and NMFS in the consultation process so that consistent and compatible opinions or findings can be adopted by both federal and State agencies.

Natural Community Conservation Planning

Adopted in 1991, California's Natural Community Conservation Planning Act establishes a program to identify the habitat needs of species before they become listed as threatened or endangered, and to develop appropriate voluntary conservation methods compatible with development and growth.

Participants in the program develop plans to protect certain habitat and will ultimately enter into agreements with DFG to ensure that the plans will be carried out. Plans must be created so that they are consistent with endangered species laws.

Dredge and Fill Permits

Section 404 of the federal Clean Water Act regulates the discharge of dredged and fill materials into waters of the United States, including wetlands. The term "discharge of dredged and fill material" has been defined broadly to include the construction of any structure involving rock, soil, or other construction material. No discharge may occur unless a permit is obtained from the US Army Corps of Engineers (USACE). Generally, the project proponent must agree to mitigate or have plans to mitigate environmental impacts caused by the project before a permit is issued. The EPA has the authority to veto permits issued by the USACE for projects that have unacceptable adverse effects on municipal water supplies, fisheries, wildlife, or recreational areas.

Section 404 allows the issuance of a general permit on a state, regional, or nationwide basis for certain categories of activities that will cause only minimal environmental effects. Such activities are permitted without the need of an individual permit application. Installation of a stream gaging station along a river levee is one example of an activity that falls within a nationwide permit.

The USACE also administers a permitting program under Section 10 of the 1899 Rivers and Harbors Act. Section 10 generally requires a permit for obstructions to navigable water. The scope of the permit under Section 10 is narrower than under Section 404 since the term "navigable waters" is more limited than "waters of the United States."

The majority of water development projects must comply with Section 404, Section 10, or both.

Public Interest Terms and Conditions

The Water Code authorizes the SWRCB to impose public interest terms and conditions to conserve the public interest, specifically the consideration of instream beneficial uses, when it issues permits to appropriate water.

Local General Plans and Specific Plans

Local (city and county) general plans and specific plans provide methods to manage and protect fish and wildlife. The Conservation element of a plan provides direction and objectives for the conservation, development and use of natural resources. The Open-Space element of a plan guides the comprehensive, long-range preservation and conservation of open space lands including water bodies.

Releases of Water for Fish

Fish and Game Code Section 5937 provides protection to fisheries by requiring that the owner of any dam allow sufficient water at all times to pass through the dam to keep in good condition any fisheries that may be planted or exist below the dam. In *California Trout, Inc. v. the State Water Resources Control Board* (1989), the court determined that Fish and Game Code sections 5937 and 5946 required the SWRCB to modify the permits and licenses issued to the City of Los Angeles to appropriate water from the streams feeding Mono Lake to ensure sufficient water flows for downstream fisheries. The SWRCB reconsidered Los Angeles' permits and licenses in light of Fish and Game Code Section 5937 and the

public trust doctrine. In 1994, the SWRCB adopted D-1631, which requires Los Angeles to allow sufficient flows from the streams feeding Mono Lake to reach the lake to allow it to rise to the level of 6,391 feet in approximately twenty years.

Streambed Alteration Agreements

Fish and Game Code Sections 1601 and 1603 require that any governmental entity or private party altering a river, stream, lakebed, bottom, or channel enter into an agreement with DFG. When the project may substantially impact an existing fish or wildlife resource, DFG may require that the agreement include provisions designed to protect riparian habitat, fisheries, and wildlife. New water development projects and ongoing maintenance activities are often subject to these sections.

Migratory Bird Treaty Act

This act implements various treaties for the protection of migratory birds and prohibits the "taking" (broadly defined) of birds protected by those treaties without a permit. The Secretary of the Interior determines conditions under which a taking may occur, and criminal penalties are provided for unlawfully taking or transporting protected birds. Liability imposed by this act was one of several factors leading to the decision to close the San Luis Drain and Kesterson Reservoir.

Fish and Wildlife Coordination Act

The Fish and Wildlife Coordination Act expresses congressional policy to protect the quality of the aquatic environment as it affects the conservation, improvement, and enjoyment of fish and wildlife resources. Under this act, any federal agency that proposes to control or modify any body of water, or to issue a permit allowing control or modification of a body of water, must first consult with the USFWS and State wildlife officials. This requires coordination early in the project planning and environmental review processes.

CVPIA

In 1992, the Central Valley Project Improvement Act (Title 34 of PL 102-575) made significant changes to the CVP's legislative authorization, amending the project's purposes to place fish and wildlife mitigation and restoration on a par with water supply, and to place fish and wildlife enhancement on a par with power generation.

Major Provisions of CVPIA (1992)

- No new CVP water supply contracts for purposes other than fish and wildlife (with a few limited exceptions) until all environmental restoration actions specified in the act have been completed.
- Allows transfers of project water to users outside of the CVP service area, under numerous specified conditions including a right of first refusal to a proposed transfer by existing CVP water users (under the same terms and conditions specified in the proposed transfer), and a requirement that proposed transfers of more than 20 percent of a contracting agency's project water supply be subject to review and approval by the contracting agency.
- Requires DOI to develop water conservation criteria, and to review conservation plans submitted by contracting agencies pursuant to Reclamation Reform Act requirements for conformance to the CVPIA criteria. Tiered pricing is to be included in CVP water supply contracts when they are renewed. Project water supply and repayment contractors' surface water delivery systems are to be equipped with water measurement devices.
- All reasonable efforts to double, by 2002, natural production (based on 1967-91 fishery population levels) of specified anadromous fish in the Central Valley, and to implement that program. A portion of the San Joaquin River is exempted from this provision.)
- Dedication of 800 taf/yr of CVP yield to fish and wildlife purposes, and acquisition of supplemental water for meeting the fish doubling goal.
- An annual Trinity River instream flow of at least 340 taf through 1996, via releases from Lewiston Dam, with subsequent instream flow requirements to be determined by a USFWS instream flow study.
- Deliver water corresponding to existing non-firm supplies to specified federal, State, and private wildlife refuges in the Sacramento and San Joaquin Valleys. DOI is to acquire, from willing sellers, an additional increment of water supply for the wildlife areas, corresponding to their full habitat development needs. All of the supplemental water needs are to be met by 2002.
- Implementation of numerous specified environmental restoration actions, such as remedying fish passage problems at Red Bluff Diversion Dam, replenishing spawning gravel, and assisting in screening non-federal diversions.
- Preparation of specified reports and studies including a least-cost plan to replace the 800 taf/yr of project yield dedicated to environmental purposes, and an evaluation of water supply and development requirements for 120,000 acres of wetlands identified in a Central Valley Habitat Joint Venture report.
- A land retirement program, and specifies categories of land that may be acquired. San Joaquin Valley drainage-impaired lands are among the authorized categories.
- CVPIA restoration fund within the federal treasury to collect mitigation and restoration payments from project water and power users.

Water Allocation, Use and Regulation in California

Several statutes designed to set aside resources or areas to preserve their natural conditions for habitat, watershed protection, recreational, and scenic values also affect water use and management. These statutes preclude many activities, including most water development projects, within the areas set aside.

State and Federal Wild and Scenic Rivers System

In 1968, Congress passed the National Wild and Scenic Rivers Act to preserve, in their free flowing condition, rivers which possess "outstandingly remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural, or other similar values." The act also states " . . . that the established national policy of dam and other construction at appropriate sections of rivers of the United States needs to be complemented by a policy that would preserve other selected rivers or sections thereof in their free flowing condition to protect the water quality of such rivers and to fulfill other vital national conservation purposes."

The act prohibits federal agencies from constructing, authorizing, or funding the construction of water resources projects having a direct and adverse effect on the values for which a river was designated. This restriction also applies to rivers designated for potential addition to the National Wild and Scenic Rivers System. Included in the system are most rivers protected under California's State Wild and Scenic Rivers Act; these rivers were included in the national system upon California's petition on January 19, 1981. The West Walker and East Fork Carson Rivers are not included in the federal system.

In 1972, the Legislature passed the California Wild and Scenic Rivers Act, declaring that specified rivers possess extraordinary scenic, recreational, fishery, or wildlife values, and should be preserved in a free flowing state for the benefit of the people of California. The Act declared that such use of the rivers would be the highest and most beneficial use within the meaning of Article X, Section 2 of the California Constitution. The act prohibits construction of any dam, reservoir, diversion, or other water impoundment on a designated river. Diversions needed to supply domestic water to residents of counties through which the river flows may be authorized, if the Secretary for Resources determines that the diversion will not adversely affect the river's free-flowing character. The major difference between the national and State acts is that if a river is designated wild and scenic under the State act, the Federal Energy Regulatory Commission (FERC) can still issue a license to build a dam on that river, thus overriding the State system. (See Federal Power Act later in this chapter.) This difference explains why national wild and scenic designation is often sought.

National Wilderness Act

The Wilderness Act sets up a system to protect federal land designated by Congress as a "wilderness area" and preserve it in its natural condition. Wilderness is defined as undeveloped federal land retaining its primeval character and influence without permanent improvements or human habitation. Commercial enterprise, permanent roads, motor vehicles, aircraft landings, motorized equipment, or construction of structures or installations (such as dams, diversions, conveyance facilities, and gaging stations) are prohibited within designated wilderness areas.

Watershed Management and Protection Practices

Many State and federal agencies have authority for managing and protecting watershed areas including the State Parks and Recreation system, national forest service lands, public lands administered by the Bureau of Land Management, and the national park system. Cities and Counties serve as local land management agencies that often coordinate and provide an institutional focus for watershed efforts. In

addition, local resource conservation districts and watershed groups assume active roles in management and protection for many watersheds.

Regulating Project Planning, Implementation and Mitigation

Another set of environmental statutes compels governmental agencies and private individuals to document and consider the environmental consequences of their actions. The statutes define the procedures through which governmental agencies must consider environmental factors in their decision-making process.

National Environmental Policy Act

NEPA directs federal agencies to prepare an environmental impact statement (EIS) for all major federal actions that may have a significant effect on the human environment. It states that it is the goal of the federal government to use all practicable means, consistent with other considerations of national policy, to protect and enhance the quality of the environment. It is a procedural law requiring all federal agencies to consider the environmental impacts of their proposed actions during the planning and decision-making processes.

NEPA requires preparation of an EIS to document a major Federal action that could significantly affect the quality of the human environment. An EIS includes the environmental impact of the proposed action, any adverse environmental effects which cannot be avoided should the proposal be implemented, alternatives to the proposed action, the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity, and any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented. NEPA does not generally require federal agencies to adopt mitigation measures or alternatives provided in the EIS.

California Environmental Quality Act

CEQA, modeled after NEPA, requires California public agency decision-makers to document and consider the environmental impacts of their actions. It requires an agency to identify ways to avoid or reduce environmental damage, and to implement those measures where feasible. CEQA applies to all levels of California government, including the State, counties, cities, and local districts.

CEQA requires that a public agency carrying out a project with significant environmental effects prepare an environmental impact report (EIR). An EIR contains a description of the project; a discussion of the project's environmental impacts, mitigation measures, and alternatives; public comments; and the agency's responses to the comments. In other instances, a notice of exemption from the application of CEQA may also be appropriate.

CEQA imposes substantive duties on all California governmental agencies that approve projects with significant environmental impacts to adopt feasible alternatives or mitigation measures that substantially lessen these impacts, unless there are overriding reasons. When a project is subject to both CEQA and NEPA, both laws encourage the State and federal agencies to cooperate in planning the project and to prepare joint environmental documents.

Regulations for Water Use Efficiency

Article X, Section 2 of the California Constitution prohibits the waste, unreasonable use, unreasonable method of use, or unreasonable method of diversion of water. It also declares that the conservation and use of water "shall be exercised with a view to the reasonable and beneficial use thereof in the public interest and for the public welfare." Although provisions and requirements of the Constitution are self-executing, the Constitution states that the Legislature may enact statutes to advance its policy. Water Code Section 275 directs the Department and SWRCB to "take all appropriate proceedings or actions before executive, legislative, or judicial agencies to prevent waste or unreasonable use of water." SWRCB's Water Right Decision 1600, directing the Imperial Irrigation District to adopt a water conservation plan, is an example of an action brought under Article X, Section 2. SWRCB's authority to order preparation of such a plan was upheld in 1990 by the courts in Imperial Irrigation District v. State Water Resources Control Board. Other complaints have been pending before the Board for years including some which pose the question of whether continued irrigation of soils known to contain toxic concentrations of selenium and other contaminants constitute either reasonable or beneficial use when measured against their known impacts.

Urban Water Management Planning Act

Since 1983, this act has required urban water suppliers that serve more than 3,000 customers or more than 3,000 af/yr to prepare and adopt urban water conservation plans. The act authorizes the supplier to implement the water conservation program. The plans must contain several specified elements, including estimates of water use, identification of existing conservation measures, identification of alternative conservation measures, a schedule of implementation of actions proposed by the plan, and identification of the frequency and magnitude of water shortages. In 1991, the act was amended in response to the drought to require water suppliers to estimate water supplies available at the end of one, two, and three years, and to develop contingency plans for severe shortages. The act also requires water suppliers to review and update their plans at least once every five years. New requirements for urban water management plans are periodically passed by the State legislature (see SB 610, SB 672, and SB 1518 in Section 2.6.9).

Water Conservation in Landscaping Act

The Water Conservation in Landscaping Act required the Department, with the assistance of an advisory task force, to adopt a model water-efficient landscape ordinance. The model ordinance was adopted in August 1992, and has been codified in Title 23 of the California Code of Regulations. It establishes methods of conserving water through water budgeting plans, plant use, efficient irrigation, and auditing.

Cities and counties were required to review the model ordinance and adopt a water-efficient landscape ordinance by January 1, 1993, if they had not done so already. Alternatively, cities and counties could make a finding that such an ordinance is unnecessary due to climatic, geological, or topographic conditions, or water availability. If a city or county failed to adopt a water efficient landscape ordinance or make findings by January 31, 1993, the model ordinance became effective in that jurisdiction.

Agricultural Water Management Planning Act

Under this act, agricultural water suppliers supplying more than 50 taf of water annually were required to submit a report to the Department indicating whether a significant opportunity exists to conserve water or reduce the quantity of highly saline or toxic drainage water through improved irrigation water

management. The act provided that agricultural water suppliers who indicated that they had an opportunity to conserve water or reduce the quantity of highly saline or toxic water should prepare a water management plan and submit it to the DWR.

Agricultural Water Suppliers Efficient Management Practices Act

The Agricultural Water Suppliers Efficient Management Practices Act, adopted in 1990, required that DWR establish an advisory committee to review efficient agricultural water management practices. Under the act, DWR was required to offer assistance to agricultural water suppliers seeking to improve the efficiency of their water management practices. The committee developed a Memorandum of Understanding to implement the practices, and to establish an Agricultural Water Management Council. The advisory committee adopted the MOU in October 1996. The MOU was declared in effect in May 1997 after 15 agricultural water suppliers, representing 2 million irrigated acres, had signed. The Council was established and held its first meeting in July 1997. The Council consists of members of the agricultural and environmental communities and other interested parties with the expressed goal for water suppliers to voluntarily develop Water Management Plans and implement Efficient Water Management Practices (EWMPs) to further advance water use efficiency while maintaining and enhancing economic, environmental and social viability and sustainability of soil and crop production.

Agricultural Water Conservation and Management Act of 1992 (AB3616, Statutes of 1992)

This act gives any public agency that supplies water for agricultural use authority to institute water conservation or efficient management programs. The programs can include irrigation management services, providing information about crop water use, providing irrigation consulting services, improving the supplier's delivery system, providing technical and financial assistance to farmers, encouraging conservation through pricing of water, and monitoring.

Water Recycling Act of 1991

This act describes the environmental benefits and public safety of using recycled water as a reliable and cost-effective method of helping to meet California's water supply needs. It sets a statewide goal to recycle 700 taf/yr by the year 2000 and 1 maf/yr by 2010.

CALFED Water Use Efficiency Program

CALFED's Water Use Efficiency Program encourages investments in water use efficiency primarily through its competitive grant/loan program.

Other Regulations

Federal Power Act. The Federal Power Act created a federal licensing system administered by the Federal Energy Regulatory Commission and required that a license be obtained for nonfederal hydroelectric projects proposing to use navigable waters or federal lands. The act contains a clause modeled after a clause in the Reclamation Act of 1902, which disclaims any intent to affect state water rights law. In a number of decisions dating back to the 1940s, the U.S. Supreme Court has attempted to interpret the clause. In some cases they have upheld states rights and in others have held that federal law prevents any state regulation of federally licensed power projects other than determining proprietary water rights. Most recently, in 1994, the U.S. Supreme Court issued a decision referred to as the Elkhorn decision or Tacoma decision (PUD No. 1 of Jefferson County and City of Tacoma v. Washington Department of Ecology) that upheld the state's minimum instream flow requirement as a permissible condition of a Clean Water Act Section 401 certification.

Water Bonds

Voters have approved three additional major California water bonds since the last Water Plan Update:

- **Proposition 13.** In March 2000, California voters approved Proposition 13 (2000 Water Bond), which authorizes the State of California to sell \$1.97 billion in general obligation bonds to support safe drinking, water quality, flood protection and water reliability projects throughout the State.
- **Proposition 40.** In March 2002, California voters approved Proposition 40, a \$2.6 billion state bond measure for conservation, neighborhood parks, and coastline and watershed protection. Proposition 40 was the largest conservation bond measure ever approved in California.
- **Proposition 50.** In November 2002, the \$3.4 billion water bond measure, the largest in California history, was approved by voters. It provides 825 million in funding for CALFED for a variety of programs, including surface water storage studies, water conveyance facilities, levee improvements, water supply reliability projects, ecosystem restoration, watershed programs, conservation and water recycling. (More on Proposition 50 is available at www.water.ca.gov/grants-loans.)

Water Plan Legislation

Legislation that is directly related to the California Water plan is listed in this article.

CALIFORNIA WATER CODE SECTION 10004-10013

DIVISION 6. CONSERVATION, DEVELOPMENT, AND UTILIZATION OF STATE WATER RESOURCES

PART 1. ADOPTION OF STATE WATER PLAN 10000-10003

PART 1.5. THE CALIFORNIA WATER PLAN 10004-10013

10004. (a) The plan for the orderly and coordinated control, protection, conservation, development, and utilization of the water resources of the state which is set forth and described in Bulletin No. 1 of the State Water Resources Board entitled "Water Resources of California," Bulletin No. 2 of the State Water Resources Board entitled, "Water Utilization and Requirements of California," and Bulletin No. 3 of the department entitled, "The California Water Plan," with any necessary amendments, supplements, and additions to the plan, shall be known as "The California Water Plan."

(b) (1) The department shall update The California Water Plan on or before December 31, 2003, and every five years thereafter. The department shall report the amendments, supplements, and additions included in the updates of The California Water Plan, together with a summary of the department's conclusions and recommendations, to the Legislature in the session in which the updated plan is issued. ((2) The department shall establish an advisory committee, comprised of representatives of agricultural and urban water suppliers, local government, business, production agriculture, and environmental interests, and other interested parties, to assist the department in the updating of The California Water Plan. The department shall consult with the advisory committee in carrying out this section. The department shall provide written notice of meetings of the advisory committee to any interested person or entity that request the notice. The meetings shall be open to the public.

(3) The department shall release a preliminary draft of The California Water Plan, as updated, upon request, to interested persons and entities throughout the state for their review and comments. The department shall provide these persons and entities an opportunity to present written or oral comments on the preliminary draft. The department shall consider these comments in the preparation of the final publication of The California Water Plan, as updated.

10004.5. As part of the requirement of the department to update The California Water Plan pursuant to subdivision (b) of Section 10004, the department shall include in the plan a discussion of various strategies, including, but not limited to, those relating to the development of new water storage facilities, water conservation, water recycling, desalination, conjunctive use, and water transfers that may be pursued in order to meet the future water needs of the state. The department shall also include a discussion of the potential for alternative water pricing policies to change current and projected uses. The department shall include in the plan a discussion of the potential advantages and disadvantages of each strategy and an identification of all federal and state permits, approvals, or entitlements that are anticipated to be required in order to implement the various components of the strategy.

10004.6. (a) As part of updating The California Water Plan every five years pursuant to subdivision (b) of Section 10004, the department shall conduct a study to determine the amount of water needed to meet

the state's future needs and to recommend programs, policies, and facilities to meet those needs. (b) The department shall consult with the advisory committee established pursuant to subdivision (b) of Section 10004 in carrying out this section.

(c) On or before January 1, 2002, and one year prior to issuing each successive update to The California Water Plan, the department shall release a preliminary draft of the assumptions and other estimates upon which the study will be based, to interested persons and entities throughout the state for their review and comments. The department shall provide these persons and entities an opportunity to present written or oral comments on the preliminary draft. The department shall consider these documents when adopting the final assumptions and estimates for the study. For the purpose of carrying out this subdivision, the department shall release, at a minimum, assumptions and other estimates relating to all of the following:

(1) Basin hydrology, including annual rainfall, estimated unimpaired stream flow, depletions, and consumptive uses.

(2) Groundwater supplies, including estimates of sustainable yield, supplies necessary to recover overdraft basins, and supplies lost due to pollution and other groundwater contaminants.

(3) Current and projected land use patterns, including the mix of residential, commercial, industrial, agricultural, and undeveloped lands.

(4) Environmental water needs, including regulatory instream flow requirements, nonregulated instream uses, and water needs by wetlands, preserves, refuges, and other managed and unmanaged natural resource lands.

(5) Current and projected population.

(6) Current and projected water use for all of the following:

(A) Interior uses in a single-family dwelling.

(B) Exterior uses in a single-family dwelling.

(C) All uses in a multifamily dwelling.

(D) Commercial uses.

(E) Industrial uses.

(F) Parks and open spaces.

(7) Evapotranspiration rates for major crop types, including estimates of evaporative losses by irrigation practice and the extent to which evaporation reduces transpiration.

(8) Current and projected adoption of urban and agricultural conservation practices.

(9) Current and projected supplies of water provided by water recycling and reuse.

(d) The department shall include a discussion of the potential for alternative water pricing policies to change current and projected water uses identified pursuant to paragraph (6) of subdivision (c).

(e) Nothing in this section requires or prohibits the department from updating any data necessary to update The California Water Plan pursuant to subdivision (b) of Section 10004.

10005. (a) It is hereby declared that the people of the state have a primary interest in the orderly and coordinated control, protection, conservation, development, and utilization of the water resources of the state by all individuals and entities and that it is the policy of the state that The California Water Plan, with any necessary amendments, supplements, and additions to the plan, is accepted as the master plan which guides the orderly and coordinated control, protection, conservation, development, management and efficient utilization of the water resources of the state.

(b) The declaration set forth in subdivision (a) does not constitute approval for the construction of specific projects or routes for transfer of water, or for financial assistance, by the state, without further legislative action, nor shall the declaration be construed as a prohibition of the development of the water

resources of the state by any entity.

10005.1. The department or, at the department's request, the California Water Commission, shall conduct a series of hearings with interested persons, organizations, local, state, and federal agencies, and representatives of the diverse geographical areas and interests of the state.

10005.2. Prior to holding a hearing pursuant to Section 10005.1, the department shall give notice by mail of the hearing to persons and entities which have requested notice and have provided their name and address to the department.

10006. The provisions of this part do not repeal or modify any of the provisions of Part 3 of this division.

10007. Notwithstanding anything contained in this part, all applications heretofore filed by the Department of Finance or by the Department of Water Resources under Part 2 of Division 6 shall remain valid and shall retain and have the status and priority accorded to such applications as now or hereafter provided in said Part 2.

10008. The Legislature hereby finds and declares that agreements which provide for the transfer of water from the federal Central Valley Project to public entities supplying water for domestic or irrigation use offer potential benefits to California's hard-pressed farmers and to California's water-dependent urban areas. It is the intent of the Legislature that these contracts be entered into for the purposes of strengthening California's economy, serving the public, and protecting the environment.

The director shall continue to pursue negotiations with the United States Bureau of Reclamation to contract for the interim rights to stored water from the federal Central Valley Project for use in the State Water Resources Development System by state water supply contractors.

10009. The director shall pursue discussions with the United States Bureau of Reclamation to permit persons and public entities which have entitlements to water from the federal Central Valley Project, to enter into legally binding contracts with any public entity which supplies water for domestic use, irrigation use, or environmental protection in this state for the transfer of federal water entitlements during times of shortage.

10011. (a) In preparing the California Water Plan, the director shall conduct at least one public hearing within the boundaries of the Sacramento-San Joaquin Delta, and shall solicit the comments of water agencies within the delta, agricultural groups representative of delta agricultural activity, environmental groups concerned with protecting delta wildlife habitat, and groups representative of those who utilize water exported from the delta.

(b) The California Water Plan shall include a discussion of various alternatives, including their advantages and disadvantages, for improving and protecting the current uses and configuration of the Sacramento-San Joaquin Delta.

(c) Subdivisions (a) and (b) shall be implemented only to the extent money is appropriated in the annual Budget Act to carry out this section.

10013. (a) The department, as a part of the preparation of the department's Bulletin 160-03, shall include in the California Water Plan a report on the development of regional and local water projects within each hydrologic region of the state, as described in the department's Bulletin 160-98, to improve water supplies to meet municipal, agricultural, and environmental water needs and minimize the need to import water

from other hydrologic regions. The report shall include, but is not limited to, regional and local water projects that use technologies for desalting brackish groundwater and ocean water, reclaiming water for use within the community generating the water to be reclaimed, the construction of improved potable water treatment facilities so that water from sources determined to be unsuitable can be used, and the construction of dual water systems and brine lines, particularly in connection with new developments and when replacing water piping in developed or redeveloped areas.

SB (1341) Burton Bill

Following the publishing of the last California Water Plan update in 1998, the Legislature asked DWR to make public all assumptions and estimates that will be used in the next update.

Sen. John Burton carried the legislation that was enacted in 2000 (SB1341 can be found [here](#)). It requires a report about the update's assumptions and estimates: this Web site.

At a minimum, the law says, the A&E Report will include information on all water categories specified by the California Water Code. Those categories can be found in the Burton Bill table.

Text of SB 1341 (Burton Bill)

BILL NUMBER: SB 1341 CHAPTERED

BILL TEXT

CHAPTER 720

FILED WITH SECRETARY OF STATE SEPTEMBER 27, 2000

APPROVED BY GOVERNOR SEPTEMBER 25, 2000

PASSED THE SENATE AUGUST 31, 2000

PASSED THE ASSEMBLY AUGUST 30, 2000

AMENDED IN ASSEMBLY AUGUST 7, 2000

AMENDED IN SENATE JULY 5, 2000

AMENDED IN SENATE MAY 30, 2000

AMENDED IN SENATE APRIL 24, 2000

INTRODUCED BY Senator Burton

(Coauthor: Assembly Member Machado)

JANUARY 10, 2000

An act to amend Sections 10004 and 10004.5 of, and to add Section 10004.6 to, the Water Code, relating to water.

LEGISLATIVE COUNSEL'S DIGEST

SB 1341, Burton. Water resources.

Under existing law, the Department of Water Resources operates the State Water Project and exercises specified water planning functions. Existing law requires the department to update The California Water Plan, which is a plan for the conservation, development, and use of the water resources of the state, every 5 years. This bill would require the department to update The California Water Plan on or before December 31 2003, and every 5 years thereafter. The bill would require the department to provide written notice to interested persons of meetings of a prescribed advisory committee that assists the department in updating The California Water Plan. The bill would require the department to include in the California Water Plan a discussion of the potential for alternative water pricing policies, as prescribed. The bill would require the department, as part of updating The California Water Plan, to conduct a study to determine the amount of water needed to meet the state's future needs and to recommend programs, policies, and facilities to meet those needs, as prescribed. The bill would require the department, by

January 1, 2002, and one year prior to issuing each successive update to The California Water Plan, to release a preliminary draft of the assumptions and estimates upon which the study will be based. The bill would make related findings and declarations.

THE PEOPLE OF THE STATE OF CALIFORNIA DO ENACT AS FOLLOWS:

SECTION 1. The Legislature finds and declares all of the following:

(a) A long-term, reliable supply of water is essential to protect and enhance California's natural resources and economic climate.

(b) While the Department of Water Resources has projected that Californians will experience chronic water shortages in the future, the Legislature has heard credible testimony from a number of different interest groups calling into question the accuracy of those estimates.

(c) Without credible and accurate estimates of water supply needs, it is impossible to ensure that water programs, policies, and investments are appropriate to meet all residential, commercial, industrial, agricultural, and environmental needs.

(d) CALFED's recent hearings on its draft environmental documents showed that there are widely disparate views on the role additional surface water storage should play in meeting the state's future water needs. Some argue that the state's water needs can all be met through water conservation, reuse, and other nonstructural methods. Others argue that to protect current and future uses of water, additional surface storage is essential.

(e) To reconcile these views, and to ensure the state makes appropriate investments in water programs, policies, and facilities, there needs to be a credible and objective assessment of the state's future water supply needs.

SEC. 2. Section 10004 of the Water Code is amended to read:

10004. (a) The plan for the orderly and coordinated control, protection, conservation, development, and utilization of the water resources of the state which is set forth and described in Bulletin No. 1 of the State Water Resources Board entitled "Water Resources of California," Bulletin No. 2 of the State Water Resources Board entitled, "Water Utilization and Requirements of California," and Bulletin No. 3 of the department entitled, "The California Water Plan," with any necessary amendments, supplements, and additions to the plan, shall be known as "The California Water Plan."

(b) (1) The department shall update The California Water Plan on or before December 31, 2003, and every five years thereafter. The department shall report the amendments, supplements, and additions included in the updates of The California Water Plan, together with a summary of the department's conclusions and recommendations, to the Legislature in the session in which the updated plan is issued.

(2) The department shall establish an advisory committee, comprised of representatives of agricultural and urban water suppliers, local government, business, production agriculture, and environmental interests, and other interested parties, to assist the department in the updating of The California Water Plan. The department shall consult with the advisory committee in carrying out this section. The department shall provide written notice of meetings of the advisory committee to any interested person or entity that request the notice. The meetings shall be open to the public. (3) The department shall release a preliminary draft of The California Water Plan, as updated, upon request, to interested persons and entities throughout the state for their review and comments. The department shall provide these persons and entities an opportunity to present written or oral comments on the preliminary draft. The department shall consider these comments in the preparation of the final publication of The California Water Plan, as updated.

SEC. 3. Section 10004.5 of the Water Code is amended to read:

10004.5. As part of the requirement of the department to update The California Water Plan pursuant to subdivision (b) of Section 10004, the department shall include in the plan a discussion of various

strategies, including, but not limited to, those relating to the development of new water storage facilities, water conservation, water recycling, desalination, conjunctive use, and water transfers that may be pursued in order to meet the future water needs of the state. The department shall also include a discussion of the potential for alternative water pricing policies to change current and projected uses. The department shall include in the plan a discussion of the potential advantages and disadvantages of each strategy and an identification of all federal and state permits, approvals, or entitlements that are anticipated to be required in order to implement the various components of the strategy.

SEC. 4. Section 10004.6 is added to the Water Code, to read:

10004.6. (a) As part of updating The California Water Plan every five years pursuant to subdivision (b) of Section 10004, the department shall conduct a study to determine the amount of water needed to meet the state's future needs and to recommend programs, policies, and facilities to meet those needs.

(b) The department shall consult with the advisory committee established pursuant to subdivision (b) of Section 10004 in carrying out this section.

(c) On or before January 1, 2002, and one year prior to issuing each successive update to The California Water Plan, the department shall release a preliminary draft of the assumptions and other estimates upon which the study will be based, to interested persons and entities throughout the state for their review and comments. The department shall provide these persons and entities an opportunity to present written or oral comments on the preliminary draft. The department shall consider these documents when adopting the final assumptions and estimates for the study. For the purpose of carrying out this subdivision, the department shall release, at a minimum, assumptions and other estimates relating to all of the following:

(1) Basin hydrology, including annual rainfall, estimated unimpaired stream flow, depletions, and consumptive uses.

(2) Groundwater supplies, including estimates of sustainable yield, supplies necessary to recover overdraft basins, and supplies lost due to pollution and other groundwater contaminants.

(3) Current and projected land use patterns, including the mix of residential, commercial, industrial, agricultural, and undeveloped lands.

(4) Environmental water needs, including regulatory instream flow requirements, nonregulated instream uses, and water needs by wetlands, preserves, refuges, and other managed and unmanaged natural resource lands.

(5) Current and projected population.

(6) Current and projected water use for all of the following:

(A) Interior uses in a single-family dwelling.

(B) Exterior uses in a single-family dwelling.

(C) All uses in a multifamily dwelling.

(D) Commercial uses.

(E) Industrial uses.

(F) Parks and open spaces.

(7) Evapotranspiration rates for major crop types, including estimates of evaporative losses by irrigation practice and the extent to which evaporation reduces transpiration.

(8) Current and projected adoption of urban and agricultural conservation practices.

(9) Current and projected supplies of water provided by water recycling and reuse.

(d) The department shall include a discussion of the potential for alternative water pricing policies to change current and projected water uses identified pursuant to paragraph (6) of subdivision (c).

(e) Nothing in this section requires or prohibits the department from updating any data necessary to update The California Water Plan pursuant to subdivision (b) of Section 10004.

SB (672) Machado Bill

SB 672 requires the state to include in the California Water Plan, which is prepared every five years, a report on the development of regional and local water projects, within each hydrologic region. Projects that use technologies such as desalinization, reclamation, and recycling will be included in the report. This is important because the capability of better utilizing all water sources, such as rainfall, snow melt, surface water, groundwater, ocean water or reclaimed wastewater, is a reality that can help these regions meet their own water needs without having to look elsewhere for water supplies.

BILL NUMBER: Senate Bill 672 CHAPTERED

BILL TEXT

CHAPTER 320

FILED WITH SECRETARY OF STATE SEPTEMBER 20, 2001

APPROVED BY GOVERNOR SEPTEMBER 19, 2001

PASSED THE SENATE SEPTEMBER 4, 2001

PASSED THE ASSEMBLY AUGUST 30, 2001

AMENDED IN ASSEMBLY JULY 14, 2001

AMENDED IN ASSEMBLY JULY 3, 2001

AMENDED IN SENATE JUNE 4, 2001

AMENDED IN SENATE APRIL 16, 2001

INTRODUCED BY Senator Machado

FEBRUARY 23, 2001

An act to amend Section 10620 of, and to add Section 10013 to, the Water Code, relating to water.

LEGISLATIVE COUNSEL'S DIGEST

SB 672, Machado. California Water Plan: urban water management plans.

- (1) Existing law requires the Department of Water Resources to update every 5 years the plan for the orderly and coordinated control, protection, conservation, development, and use of the water resources of the state, known as the California Water Plan. This bill would require the department to include in the California Water Plan a report on the development of regional and local water projects within each hydrologic region of the state to improve water supplies to meet municipal, agricultural, and environmental water needs and minimize the need to import water from other hydrologic regions.
- (2) Existing law requires every urban water supplier to prepare and adopt an urban water management plan. This bill would require an urban water supplier to describe in the plan water management tools and options used by that entity that will maximize resources and minimize the need to import water from other regions.

THE PEOPLE OF THE STATE OF CALIFORNIA DO ENACT AS FOLLOWS:

SECTION 1. The Legislature finds and declares all of the following:

- (a) The Department of Water Resources, through its contracts for delivery of water from the State Water Project, has established water entitlement objectives for approximately 4,200,000 acre feet.
- (b) Municipal, agricultural, and environmental water needs have increased beyond levels anticipated in the California Water Plan and the State Water Project has not developed water projects that will yield the quantity of water established as water entitlement objectives.
- (c) The health, safety, and well-being of the people of California will best be served by meeting the municipal, agricultural, and environmental water needs of each hydrologic region to the maximum extent practicable without diminishing the resources of other regions that are necessary to meet the present and future municipal, agricultural, and environmental needs of those regions, and while recognizing the

continuing need in the foreseeable future to move surplus supplies between regions in order to meet the municipal, agricultural, and environmental needs of the people of California.

(d) The health, safety, and well-being of the people of the State of California will best be served by employing current and developing water treatment and conservation technologies and by implementing the principles set forth in the Cobey-Porter Saline Water Conservation Law (Chapter 9 (commencing with Section 12945) of Part 6 of Division 6 of the Water Code) to the maximum extent practicable.

SEC. 2. Section 10013 is added to the Water Code, to read:

10013. (a) The department, as a part of the preparation of the department's Bulletin 160-03, shall include in the California Water Plan a report on the development of regional and local water projects within each hydrologic region of the state, as described in the department's Bulletin 160-98, to improve water supplies to meet municipal, agricultural, and environmental water needs and minimize the need to import water from other hydrologic regions. The report shall include, but is not limited to, regional and local water projects that use technologies for desalting brackish groundwater and ocean water, reclaiming water for use within the community generating the water to be reclaimed, the construction of improved potable water treatment facilities so that water from sources determined to be unsuitable can be used, and the construction of dual water systems and brine lines, particularly in connection with new developments and when replacing water piping in developed or redeveloped areas.

SEC. 3. Section 10620 of the Water Code is amended to read:

10620. (a) Every urban water supplier shall prepare and adopt an urban water management plan in the manner set forth in Article 3 (commencing with Section 10640).

(b) Every person that becomes an urban water supplier shall adopt an urban water management plan within one year after it has become an urban water supplier.

(c) An urban water supplier indirectly providing water shall not include planning elements in its water management plan as provided in Article 2 (commencing with Section 10630) that would be applicable to urban water suppliers or public agencies directly providing water, or to their customers, without the consent of those suppliers or public agencies.

(d) (1) An urban water supplier may satisfy the requirements of this part by participation in areawide, regional, watershed, or basinwide urban water management planning where those plans will reduce preparation costs and contribute to the achievement of conservation and efficient water use.

(2) Each urban water supplier shall coordinate the preparation of its plan with other appropriate agencies in the area, including other water suppliers that share a common source, water management agencies, and relevant public agencies, to the extent practicable.

(e) The urban water supplier may prepare the plan with its own staff, by contract, or in cooperation with other governmental agencies.

(f) An urban water supplier shall describe in the plan water management tools and options used by that entity that will maximize resources and minimize the need to import water from other regions.

SB (1062) Poochigian Bill

Senate Bill 1062 by Sen. Charles Poochigian requires the Department of Water Resources (DWR) to include various strategies for meeting the state's water supply needs in its updates to the California Water Plan. It also establishes an advisory committee to help DWR update the plan.

SB 1062 describes California's need for reliable water supplies, estimates of expected population growth, and the integral role water conservation, recycling, conjunctive use, desalination, and water storage play in meeting those needs.

SB 1062 requires DWR to include a discussion of various strategies and the potential advantages and disadvantages of the strategies that may be pursued in meeting the state's water supply needs in its update of Bulletin 160. Additionally the update must identify all federal and state permits, approvals or entitlements that might be required in order to implement the strategies. This narrative will serve as the basis for future informed discussions and decisions regarding California's water plan.

Finally, SB 1062 requires DWR to establish an advisory committee, comprised of representatives of agricultural and urban water suppliers, local government, business, production agriculture, environmental interests, and other interested parties, to assist in the updating of Bulletin 160.

BILL NUMBER: SB 1062 CHAPTERED

BILL TEXT

CHAPTER 210

FILED WITH SECRETARY OF STATE JULY 28, 1999

APPROVED BY GOVERNOR JULY 27, 1999

PASSED THE ASSEMBLY JULY 15, 1999

PASSED THE SENATE MAY 24, 1999

AMENDED IN SENATE APRIL 27, 1999

AMENDED IN SENATE APRIL 13, 1999

INTRODUCED BY Senator Poochigian

FEBRUARY 26, 1999

An act to amend Section 10004 of, and to add Section 10004.5 to, the Water Code, relating to water.

LEGISLATIVE COUNSEL'S DIGESTS

B 1062, Poochigian. The California Water Plan.

Existing law requires the Department of Water Resources to update, every 5 years, The California Water Plan, which is the plan for the control, protection, conservation, development, and utilization of the water resources of the state.

This bill would require the department to establish a prescribed advisory committee to assist the department in the updating of the plan. The bill would require the department, in connection with the updating of the plan, to include in the plan a discussion of various strategies, including those strategies relating to the development of new water storage facilities, water conservation and recycling, desalination, conjunctive use, and water transfers, that may be pursued to meet the future water needs of the state, as prescribed. The bill would make related legislative findings and declarations.

THE PEOPLE OF THE STATE OF CALIFORNIA DO ENACT AS FOLLOWS:

SECTION 1. The Legislature finds and declares all of the following:

- (a) A long-term, reliable supply of water is essential to protect the productivity of California's businesses and economic climate.
- (b) The Department of Finance projects that California's population will increase to over 47 million persons by 2020, increasing the need for the development of additional safe and reliable water supplies that are critical to the health, safety, and welfare of all Californians, including the state's future generations.
- (c) Water-related infrastructure investment needs are growing rapidly as a result of a growing population and economy, environmental and public health requirements, and aging water delivery systems.
- (d) The Department of Water Resources projects that Californians will experience chronic water shortages, as early as 2000, unless actions are taken to increase the amount of developed water available for use in California.

(e) Water conservation, water recycling, voluntary water transfers, conjunctive use, and desalination programs and projects will continue to be an integral part of California's water management strategy.(f) The review, planning, and development of new water storage facilities and the renewed operation or enlargement of existing water storage facilities should be pursued to ensure that a reliable, high quality supply of water is available to meet the current and future needs of all beneficial uses of water, including urban, agricultural, and environmental uses.

SEC. 2. Section 10004 of the Water Code is amended to read:

10004. (a) The plan for the orderly and coordinated control, protection, conservation, development, and utilization of the water resources of the state which is set forth and described in Bulletin No. 1 of the State Water Resources Board entitled "Water Resources of California," Bulletin No. 2 of the State Water Resources Board entitled, "Water Utilization and Requirements of California," and Bulletin No. 3 of the department entitled, "The California Water Plan," with any necessary amendments, supplements, and additions to the plan, shall be known as "The California Water Plan."

(b) (1) The department shall update The California Water Plan every five years. The department shall report the amendments, supplements, and additions included in the updates of The California Water Plan, together with a summary of the department's conclusions and recommendations, to the Legislature in the session in which the updated plan is issued.(2) The department shall establish an advisory committee, comprised of representatives of agricultural and urban water suppliers, local government, business, production agriculture, and environmental interests, and other interested parties, to assist the department in the updating of The California Water Plan. The department shall consult with the advisory committee in carrying out this section.

(3) The department shall release a preliminary draft of The California Water Plan, as updated, upon request, to interested persons and entities throughout the state for their review and comments. The department shall provide these persons and entities an opportunity to present written or oral comments on the preliminary draft. The department shall consider these comments in the preparation of the final publication of The California Water Plan, as updated.

SEC. 3. Section 10004.5 is added to the Water Code, to read:

10004.5. As part of the requirement of the department to updateThe California Water Plan pursuant to subdivision (b) of Section

10004, the department shall include in the plan a discussion of various strategies, including, but not limited to, those relating to the development of new water storage facilities, water conservation, water recycling, desalination, conjunctive use, and water transfers that may be pursued in order to meet the future water needs of the state. The department shall include in the plan a discussion of the potential advantages and disadvantages of each strategy and an identification of all federal and state permits, approvals, or entitlements that are anticipated to be required in order to implement the various components of the strategy.

AB (2587) Matthews Bill

AB 2587 requires the California Department of Water Resources to consider scenarios in the California Water Plan Update that are consistent with substantial continued agricultural production in California. A key phrase in the law is that "neither the state nor the nation should be allowed to become dependent upon a net import of foreign food." In particular, the law specifies that DWR consider scenarios under which agricultural production in California is sufficient to assure that California is a net food exporter and that the net shipments out of state are enough to cover 25 percent of "table food" use in United States plus "growth in export markets." The 25 percent share is taken to be the traditional share from California.

Text of AB 2587 (Matthews Bill)

BILL NUMBER: AB 2587 CHAPTERED

BILL TEXT

CHAPTER 615

FILED WITH SECRETARY OF STATE SEPTEMBER 17, 2002

APPROVED BY GOVERNOR SEPTEMBER 16, 2002

PASSED THE ASSEMBLY AUGUST 28, 2002

PASSED THE SENATE AUGUST 27, 2002

AMENDED IN SENATE AUGUST 5, 2002

AMENDED IN ASSEMBLY MAY 23, 2002

AMENDED IN ASSEMBLY MAY 1, 2002

AMENDED IN ASSEMBLY APRIL 18, 2002

INTRODUCED BY Assembly Member Matthews

FEBRUARY 21, 2002

An act to add Section 411 to the Food and Agricultural Code,
relating to food.

LEGISLATIVE COUNSEL'S DIGEST

AB 2587, Matthews. Food: water usage forecasts.

Existing law establishes the Department of Food and Agriculture
and charges it with various duties and obligations.

This bill would require the Department of Food and Agriculture to
estimate food, fiber, livestock, and other farm products production,
as specified, and provide that information to the Department of Water
Resources for estimating related water usage, and the Chairs of the
Assembly Committee on Agriculture, the Assembly Committee on Water,
Parks, and Wildlife, and the Senate Committee on Agriculture and
Water Resources, as specified, for inclusion in a bulletin by the
Department of Water Resources estimating the state's water needs.
This bill would also state the intent of the Legislature in regard to
that bulletin.

THE PEOPLE OF THE STATE OF CALIFORNIA DO ENACT AS FOLLOWS:

SECTION 1. It is the intent of the Legislature that the food
forecasts made by the Department of Food and Agriculture and the
Department of Water Resources shall include the following
considerations:

- (1) Neither the state nor the nation should be allowed to become
dependent upon a net import of foreign food.
- (2) As the nation's population grows, California should produce
enough food to supply the state and also continue to supply the
historical proportion of the nation's food supply, approximately 25
percent of the nation's table food.
- (3) Countries such as Japan are heavily dependent on imported
food, some of which comes from California. California is also called

upon to ship food to prevent famines and to protect our national interest by providing food to maintain stability elsewhere in the world. Consideration should be given to maintaining the state's ability to meet these export needs.

SEC. 2. Section 411 is added to the Food and Agricultural Code, to read:

411. (a) The Department of Food and Agriculture shall supply the Department of Water Resources with a forecast that estimates the amount of production of food, fiber, livestock, and other farm products.

(b) As part of the forecast, the Department of Food and Agriculture's assumptions shall be based upon 20-year estimates that include, but are not limited to, the following data:

(1) Land use conversion rates and the amount of land available for agricultural production.

(2) The growing need for food, fiber, livestock and other farm products as the state's and the nation's populations grow.

(3) Implementation of irrigation technology and other on-farm water conservation measures.

(4) Advances in crop yields and production techniques.

(5) Alternate uses of crops.

(c) The department shall include an additional table in the forecast that estimates the agricultural water needs based upon food security considerations that include, at a minimum, the following:

(1) Population growth estimates.

(2) Production of farm products sufficient to feed the state's population, as well as continue to provide at least 25 percent of the nation's table food.

(3) Production necessary to meet the growth in export markets.

(d) To the extent feasible, the Department of Food and Agriculture may cooperate with the Department of Finance, the University of California, and other institutions and organizations in obtaining information for the forecasts.

(e) The Department of Food and Agriculture shall furnish the forecast to the Department of Water Resources for estimating related water usage, as well as to the Chairs of the Assembly Committee on Agriculture, the Assembly Committee on Water, Parks, and Wildlife, and the Senate Committee on Agriculture and Water Resources. The Department of Water Resources shall include this information in Bulletin 160.

Bagley-Keene Open Meeting Act

The Bagley-Keene Open Meeting Act governs notice and open meeting requirements for state bodies and is given as it appeared on January 1, 2002. The state body that meets and deliberates about the California Water Plan Update 2003 is our 70-member Advisory Committee.

The act declares, "It is the public policy of this state that public agencies exist to aid in the conduct of the people's business and the proceedings of public agencies be conducted openly so that the public may remain informed."

Work Plan for Meeting Legal Requirements For The California Water Plan (Water Code Sections 10004-10011)

(Requirements are listed in chronological order by scheduled completion date)

| Water Code Section | Description | Completion Date |
|--------------------|--|--|
| 10004. (b) (2). | The department shall establish and consult with an advisory committee, comprised of representatives of agricultural and urban water suppliers, local government, business, production agriculture, and environmental interests, and other interested parties, to assist the department in the updating of The California Water Plan. | Done – Jan. 2001 |
| 10004.6. (c). | On or before January 1, 2002, and one year prior to issuing each successive update to The California Water Plan, the department shall release a preliminary draft of the assumptions and other estimates upon which the study will be based, to interested persons and entities throughout the state for their review and comments. The department shall provide these persons and entities an opportunity to present written or oral comments on the preliminary draft. | Preliminary Draft – Released Dec. 2001 (see attached table for details) Done – 4 Workshops for Extended Review Forum Spring 2002 |
| 10004. (b) (1). | The department shall update The California Water Plan on or before December 31, 2003, and every five years thereafter. | Phase 1 – Aug. 2004 Public Review Draft Phase 2 – Jan. 2005 Final Water Plan |
| 10004. (b) (3). | The department shall release a preliminary draft of The California Water Plan, as updated, upon request, to interested persons and entities throughout the state for their review and comments. The department shall provide these persons and entities an opportunity to present written or oral comments on the preliminary draft. The department shall consider these comments in the preparation of the final publication of The California Water Plan, as updated. | Phase 1 – Aug. 2004 Public Review Draft Phase 2 – Sept/Oct. 2004 Public Hearings Phase 2 – Jan. 2005 Final Water Plan |
| 10004.5. | The department shall include in the plan a discussion of various strategies, including, but not limited to, those relating to the development of new water storage facilities, water conservation, water recycling, desalination, conjunctive use, and water transfers that may be pursued in order to meet the future water needs of the state. | Phase 1 – Aug. 2004 (using available information for 25 resource management strategies) |
| 10004.5. | The department shall include an identification of all federal and state permits, approvals, or entitlements that are anticipated to be required in order to implement the various components of the strategy. | Phase 1 – Aug. 2004 Public Review Draft Phase 2 – Jan. 2005 Final Water Plan |
| 10004.6 (a). | As part of updating The California Water Plan every five years, the department shall conduct a study to determine the amount of water needed to meet the state's future needs and.... | Phase 1 – Aug. 2004 (using available information) Phase 3 – July 2006 (using new studies) |

Work Plan for Meeting Legal Requirements For The California Water Plan

| Water Code Section | Description | Completion Date |
|--------------------|---|---|
| 10004.6 (a). | As part of updating The California Water Plan every five years, the department shall...recommend programs, policies, and facilities to meet future needs. | Phase 1 – Aug. 2004 (using available information for 25 resource management strategies) Phase 3 – July 2006 (using new studies) |
| 10004.6 (a). | The department shall consult with the advisory committee established pursuant to subdivision (b) of Section 10004 in carrying out this Section 10004.6 (a): determining future needs and recommending programs, policies, and programs to meet those needs. | Phase 1 – Aug. 2004 (using available information) Phase 2 – Dec. 2005 (selection of Data and Analytical Tools) Phase 3 – July 2006 (conduct new studies) |
| 10011. (b). | The California Water Plan shall include a discussion of various alternatives, including their advantages and disadvantages, for improving and protecting the current uses and configuration of the Sacramento-San Joaquin Delta. | Phase 1 – Aug. 2004 (using available information for 25 resource management strategies and CALFED input) Phase 2 – Jan. 2005 Final Water Plan |
| 10013. | The department, as a part of the preparation of the department's Bulletin 160-03, shall include in the California Water Plan a report on the development of regional and local water projects within each hydrologic region of the state, as described in the department's Bulletin 160-98, to improve water supplies to meet municipal, agricultural, and environmental water needs and minimize the need to import water from other hydrologic regions. | Phase 1 – Aug. 2004 Public Review Draft (12 Regional Reports in Volume 3 based on information compiled from regional planning efforts) Phase 2 – Jan. 2005 Final Water Plan |
| 10013. | This report shall include, but is not limited to, regional and local water projects that use technologies for desalting brackish groundwater and ocean water, reclaiming water for use within the community generating the water to be reclaimed, the construction of improved potable water treatment facilities so that water from sources determined to be unsuitable can be used, and the construction of dual water systems and brine lines, particularly in connection with new developments and when replacing water piping in developed or redeveloped areas. | Phase 1 – Aug. 2004 Public Review Draft (using available information on 25 resource management strategies) Phase 2 – Jan. 2005 Final Water Plan |
| 10004. (b) (1). | The department shall report to the Legislature in the session in which the updated plan is issued; the amendments, supplements, and additions included in the updates of the California Water Plan, together with a summary of the department's conclusions and recommendations. | Phase 1 – Sept 2004 on Public Review Draft Phase 2 – Feb 2005 on Final Water Plan |

| Water Code Section | Description | Completion Date |
|--|---|--|
| 10005.1. | The department or, at the department's request, the California Water Commission, shall conduct a series of hearings with interested persons, organizations, local, state, and federal agencies, and representatives of the diverse geographical areas and interests of the state. | Phase 2 – Sept/Oct 2004 Public Hearings |
| 10005.2. | Prior to holding the above hearings, the department shall give notice by mail of the hearings to persons and entities which have requested notice and have provided their name and address to the department. | Phase 1 – Aug 2004 (using 2,000 public distribution list) |
| 10011. (a). | In preparing the California Water Plan, the director shall conduct at least one public hearing within the boundaries of the Sacramento-San Joaquin Delta, and shall solicit the comments of water agencies within the delta, agricultural groups representative of delta agricultural activity, environmental groups concerned with protecting delta wildlife habitat, and groups representative of those who utilize water exported from the delta. | Phase 2 – Dec 2005 |
| 10004.6. (d). | The department shall include a discussion of the potential for alternative water pricing policies to change current and projected water uses identified pursuant to item (6) above. | Phase 1 – Aug. 2004 Public Review Draft (Narrative on Economic Incentives -Loans, Grants and Water Pricing) Phase 2 – Jan. 2005 Final Water Plan |
| Food and Agricultural Code Section 411 | (a) The Department of Food and Agriculture shall supply the Department of Water Resources with a forecast that estimates the amount of production of food, fiber, livestock, and other farm products. (e) The Department of Food and Agriculture shall furnish the forecast to the Department of Water Resources for estimating related water usage, as well as to the Chairs of the Assembly Committee on Agriculture, the Assembly Committee on Water, Parks, and Wildlife, and the Senate Committee on Agriculture and Water Resources. The Department of Water Resources shall include this information in Bulletin 160. | Phase 1 – Aug. 2004 Public Review Draft Agricultural Issue Center Study Report (Interim response until DWR receives CDFA food forecast) Phase 3 – July 2006 Water Plan Update 2008 (assumes DWR receives CDFA food forecast) |

Schedule for Assumptions and Estimates Specified In the California Water Code Section 10004.6 *For Current Conditions*

| Water Code Section | Description | Statewide Result Regional Results can be found on Assumptions and Estimates Web Site www.waterplan.water.ca.gov/A&E | | | Completion Date |
|--------------------|---|---|---------------------|---------------------|---|
| | | 1998 | 2000 | 2001 | |
| 10004.6. (c). | The department shall release, at a minimum, assumptions and other estimates relating to all of the following: | | | | |
| 10004.6. (c) (1). | Basin hydrology: | | | | Phase 1 – Aug. 2004 Water Portfolio Data for 1998, 2000, 2001 (with some data gaps) |
| | Annual rainfall | 329.6 maf | 187.7 maf | 139.2 maf | |
| | Unimpaired runoff ⁱ | 31.4+10.4 = 41.8 maf | 18.9+5.9 = 24.8 maf | 19.2+4.9 = 24.1 maf | |
| | Depletions ⁱⁱ | 90.8 maf | 49.7maf | 27.0 maf | |
| | Consumptive uses ⁱⁱⁱ | 19.7 maf | 25.1 maf | 25.1 maf | |
| 10004.6. (c) (2). | Groundwater supplies ^{iv} : | | | | Phase 1 – Aug 2004 Public Review Draft (using available data) |
| | Sustainable yield estimates | N/A ^v | N/A | N/A | |
| | Overdraft recovery needs ^{vi} (annual GW deficit is shown) | 1-2 maf | 4-5 maf | 9-10 maf | |
| | Supplies lost to groundwater pollution | N/A | N/A | N/A | |
| 10004.6. (c) (3). | Current land use patterns ^{vii} : | | | | Phase 1 – Aug 2004 Public Review Draft (using available data) |
| | Residential | N/A | N/A | N/A | |
| | Commercial | N/A | N/A | N/A | |
| | Industrial | N/A | N/A | N/A | |
| | Agricultural ^{viii} | 9.3 million acres | 9.0 million acres | 8.7 million acres | |
| | Undeveloped lands | N/A | N/A | N/A | |
| 10004.6. (c) (4). | Environmental water needs: | | | | Phase 1 – Aug 2004 Public Review Draft (using available data) |
| | Regulated instream flow requirements ^{ix} | 6.9 maf | 7.5 maf | 6.9 maf | |
| | Nonregulated instream flows | N/A | N/A | N/A | |
| | Wetlands and refuge needs ^x | 1.4 maf | 1.5 maf | 1.3 maf | |
| | Managed natural resource lands | N/A | N/A | N/A | |
| | Unmanaged natural resource lands | N/A | N/A | N/A | |
| | | | | | Phase 3 – Work on data gaps Water Plan Update 2008 |

| Water Code Section | Description | Statewide Result Regional Results can be found on Assumptions and Estimates Web Site www.waterplan.water.ca.gov/A&E | | | Completion Date |
|--------------------|--|---|--------------------------|--------------------------|--|
| | | 1998 | 2000 | 2001 | |
| 10004.6. (c) (5). | Current population ^{xi} : | 32.9 million people | 34.1 million people | 34.8 million people | Phase 1 – August 2004 |
| 10004.6. (c) (6). | Current Urban water needs ^{xii} : | | | | Phase 1 – Aug 2004 Public Review Draft |
| | Interior uses, single family dwelling | 1.7 maf | 2.0 maf | 2.0 maf | (using available data) |
| | Exterior uses, single family dwelling | 1.8 maf | 2.0 maf | 2.0 maf | |
| | Multifamily dwelling, all uses | 1.4 maf | 1.5 maf | 1.5 maf | |
| | Commercial water uses | 1.2 maf | 1.6 maf | 1.6 maf | Phase 3–Work on data gaps |
| | Parks & open space uses | 0.6 maf | 0.7 maf | 0.6 maf | Water Plan Update 2008 |
| 10004.6. (c) (7). | Agricultural Water | 25.4 maf | 31.9 maf | 31.6 maf | Phase 1 – Aug 2004 Public Review Draft |
| | Evapotranspiration rates for major crop types | 0.07-5.77 acre-ft/acre | 0.11-6.37 acre-ft/acre | N/A | (using available data) |
| | Evaporative losses by irrigation practice | N/A | N/A | N/A | Phase 3–Work on data gaps |
| | Evaporation impact on transpiration | N/A | N/A | N/A | Water Plan Update 2008 |
| 10004.6. (c) (8). | Adoption of agricultural conservation practices ^{xiii} . | See footnote 13 | | | Phase 1 – Aug. 2004 Public Review Draft (Narrative on Agricultural Water Use Efficiency) |
| | | | | | Phase 3–Work on data gaps Water Plan Update 2008 |
| 10004.6. (c) (8). | Adoption of urban conservation practices. | Under Development in Phase 2 – 12/2005 | | | Phase 1 – Aug. 2004 Public Review Draft (Narrative on Urban Water Use Efficiency) |
| | | | | | Phase 3–Work on data gaps Water Plan Update 2008 |
| 10004.6. (c) (9). | Water supplies from water recycling and reuse (municipal) ^{xiv} | Approx. 0.5 maf annually | Approx. 0.5 maf annually | Approx. 0.5 maf annually | Phase 1 – Aug. 2004 Public Review Draft |
| | | | | | Phase 3–Work on data gaps Water Plan Update 2008 |

For Projected Conditions

| Water Code Section | Description | Scenario 1 Current Trends Continued | Scenario 2 Resource Sustainability | Scenario 3 Resource Intensive | Completion Date |
|--------------------|---|--|--|-------------------------------------|---|
| 10004.6. (c). | The department shall release, at a minimum, assumptions and other estimates relating to all of the following: | Estimate additional 2030 urban, agricultural and environmental water demands for this scenario | | | Phase 1 – Aug. 2004 Public Review Draft (Scenario 1 with available data) Phase 3 – July 2006 (new studies for all scenarios) |
| 10004.6. (c) (3). | Projected land use patterns | | | | Phase 2 – Dec. 2005 (Select input data, analytical tools and assumptions) Phase 3 – July 2006 (new studies for all scenarios and responses for Water Plan Update 2008) |
| | Residential | | | | |
| | Commercial | | | | |
| | Industrial | | | | |
| | Agricultural | | | | |
| | Undeveloped lands | | | | |
| 10004.6. (c) (5). | Projected population ^{xv} | 48.1 million people | | | Phase 1 – August 2004 |
| 10004.6. (c) (6). | Projected urban water needs ^{xvi} | | | | Phase 2 – Dec. 2005 (Select input data, analytical tools and assumptions) Phase 3 – July 2006 (new studies for all scenarios and responses for Water Plan Update 2008) |
| | Interior uses, single family dwelling | | | | |
| | Exterior uses, single family dwelling | | | | |
| | Multifamily dwelling, all uses | | | | |
| | Commercial water uses | | | | |
| | Parks & open space uses | | | | |
| 10004.6. (c) (8). | Adoption of agricultural conservation practices. ^{xvii} | | | | Phase 2 – Dec. 2005 Update Agricultural Water Use Efficiency potential estimates using information from CALFED WUE Program & other studies) |
| 10004.6. (c) (8). | Adoption of urban conservation practices. ^{xviii} | | | | Phase 2 – Dec. 2005 Update Urban Water Use Efficiency potential estimates using information from CALFED WUE Program & other studies) |
| 10004.6. (c) (9). | Water supplies from water recycling and reuse (municipal) ^{xix} | 1.5 maf | | | Phase 1 – Aug. 2004 (Scenario 1 with available data) |

Table Footnotes

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- ⁱ From Eight River Index
- ⁱⁱ DWR, Statewide Water Balance Summary, Total Outflows to Salt Sink
- ⁱⁱⁱ DWR, Statewide Water Portfolio, Evapotranspiration of Applied Water from Agricultural, Urban and Managed Wetlands Uses
- ^{iv} Estimates of Sustainable Yield and Supplies Lost to Groundwater Pollution are not available due to the number of variables and complexity of making such estimates
- ^v Not Available
- ^{vi} DWR, Statewide Water Balance Summary, Estimates are shown for annual groundwater deficit by year. Whereas, overdraft is a long-term measure currently estimated at between 1 maf and 2 maf per year statewide (Bulletin 118-03)
- ^{vii} Land Use Patterns Statewide have not been compiled except for land in irrigated agricultural
- ^{viii} Compiled by DWR staff from Land Use Surveys and Reports from County Agricultural Commissioners
- ^{ix} DWR, Statewide Flow Diagrams, Total Required Instream Flows including flows returned to supply
- ^x DWR, Statewide Water Portfolio, Managed Wetlands Applied Water
- ^{xi} Department of Finance Projections
- ^{xii} DWR, Statewide Water Portfolio
- ^{xiii} DWR is not planning to develop information on which specific agricultural conservation practices are being used or to what level they are being adopted. Instead, DWR plans to ensure that the on-farm irrigation efficiencies, which are required to develop water use, are justifiable and agreed upon by the experts in the field. These irrigation efficiencies are an indicator of the level of water management, or conservation practices, being used.
- ^{xiv} Developed from Portfolio data received from DWR Districts
- ^{xv} Department of Finance projections – May 2004
- ^{xvi} To be developed in Phases 2 & 3 as data are available
- ^{xvii} To be developed in Phases 2 & 3 as data are available
- ^{xviii} To be developed in Phases 2 & 3 as data are available
- ^{xix} Developed from Water Portfolio data received from DWR Districts

Litigation

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| Recent Litigation in California Water Management, <i>California Department of Water Resources, Office of the Chief Counsel</i> | 3 |
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Recent Litigation in California Water Management

By California Department of Water Resources, Office of the Chief Counsel

Planning and Conservation League, Plumas County, and Santa Barbara Citizens Planning Association of Santa Barbara County v. Department of Water Resources and Central Coast Water Authority

The Planning and Conservation League filed a lawsuit on December 27, 1995, against the Department and Central Coast Water Authority, challenging the California Environmental Quality Act compliance for the Monterey Amendment. PCL amended the complaint February 13, 1996, alleging that the Department could not legally transfer the Kern Water Bank to Kern County Water Agency as part of the Monterey Amendment.

After a hearing held May 17, 1996, a Sacramento County Superior Court judge ruled in favor of the Department and CCWA on PCL's complaint and dismissed the lawsuit. PCL appealed the decision to the Third District Court of Appeal. On September 15, 2000, the Court of Appeal held that EIR was inadequate and that the Department should have acted as lead agency for the project. In addition, the Court of Appeal reversed the Superior Court's entry of summary judgment and reinstated the validation claim in the complaint, providing a forum for review of the entire Monterey Amendment and, in particular, the transfer of the Kern Fan Element of KWB.

In its decision, the Court of Appeal held the EIR was inadequate because the document should have included an analysis of Article 18(b), a standard term in the long-term water supply contracts, as part of its 'no project alternative' analysis. Article 18(b) authorized the Department to declare a permanent shortage and reduce all contractors' allocations across the board, thereby avoiding the agricultural shortage provisions. The Department believed that it was very unlikely that Article 18(b) would ever be invoked and, therefore, the elimination of Article 18(b) did not require a 'no project alternative' analysis.

The Court of Appeal adopted PCL's reasoning that local planners rely on allocation amounts in the contracts and that reductions would affect local land use planning decisions. Accordingly, the Court held that both the elimination and possible invocation of Article 18(b) needed to be evaluated for environmental impacts, and the EIR was inadequate for failure to do so. The Court directed the Department to prepare a new EIR and remanded the matter to the trial court to vacate the Department's certification of the EIR and make such other orders as appropriate.

On December 13, 2000, the California Supreme Court denied review. The parties commenced mediation on March 26, 2002, and proceedings in Superior Court were stayed pending completion of mediation. On July 18, 2002, the parties reached agreement on principles for settling the lawsuit. The Department commenced preparing a new EIR and the interested parties continued mediation to convert the settlement principles into a legal agreement. The final settlement agreement is being prepared for execution and submittal to the Superior Court for approval.

Coordinated Special Proceedings, State Water Resources Control Board Cases

On March 15, 2000, SWRCB adopted Water Rights Decision 1641, which implemented certain water quality objectives in the May 1995 Water Quality Control Plan for the Sacramento-San Joaquin Bay Delta Estuary on a long-term basis. D-1641 did not implement the Delta outflow objectives in the 1995 Plan. Those objectives were to be addressed in a subsequent water rights hearing. D-1641 also approved the joint point of diversion which allowed interchangeable use of SWP and CVP pumping facilities under certain conditions. It also approved modification of the petition to modify the place and purpose of use in the CVP permits subject to condition.

Eleven different lawsuits across the State were filed in 2000 challenging D-1641, including five in which the Department was named as a real party in interest. These lawsuits were all coordinated into one special proceeding in Sacramento Superior Court.

The case will address several important legal questions, including whether D-1641 complied with CEQA, whether the changes in D-1641 injured certain Delta water users, and whether D-1641 was consistent with area of origin laws.

The Department is supportive of D-1641 and is working in cooperation with SWRCB. The trial commenced in August 2002 and extended 16 days. The trial was completed on November 15, 2002. A decision is expected in 2003. The case is currently on appeal.

El Dorado Irrigation District v. State Water Resources Control Board

This litigation involves SWRCB Decision 1635, which approved the application by El Dorado Irrigation District to divert water for urban purposes based on the assignment of a “state filing.” “State filings” are water rights filings made by the Department (or the Department of Finance prior to 1956) as part of a general plan for State water development.

Two separate lawsuits were filed and consolidated in this case. The first lawsuit was filed by El Dorado Irrigation District and El Dorado County Water Agency, which challenged the imposition of Term 91 as part of the decision. Term 91 is a standard permit term that prohibits diverters within the Sacramento-San Joaquin watershed from diverting natural flow during the time periods that the SWP and CVP are releasing stored water to meet the Delta’s water quality objectives. The second lawsuit was filed by an environmental group, League to Save Sierra Lakes. This lawsuit alleges that SWRCB failed to comply with CEQA and improperly allocated water for urban purposes contrary to the Water Code and the public trust doctrine. The Department was not named originally in either lawsuit, but was later ruled to be indispensable party for the El Dorado litigation as a result of a motion brought by SWRCB. Consequently, the Department was later named as a party in the lawsuit in an amended petition.

If the court finds that Term 91 was improperly imposed on El Dorado as part of D-1635, the Department will be required to adjust its operations accordingly to compensate, which would affect SWP water supply. The litigation is expected to go to trial in 2003. This case is currently on appeal.

Tulare Lake Basin Water Storage District v. U.S.

In February 1998, plaintiffs Tulare, Kern, Wheeler Ridge-Maricopa Water Storage District, and others filed a claim in the U.S. Court of Federal Claims alleging that the federal government took plaintiffs' water without just compensation in violation of the Fifth Amendment of the U.S. Constitution. The plaintiffs claim that in 1992, 1993, and 1994 the U.S. Fish and Wildlife Service and National Marine Fisheries Service, under authority of the Endangered Species Act and through issuance of biological opinions for winter run salmon and Delta smelt, took their water for a public purpose without compensation. The plaintiffs claim a right to the water based on their long-term water supply contracts with the Department. The plaintiffs claimed damages of \$25,720,320 plus attorney fees and other costs.

On April 30, 2001, the U.S. Court of Federal Claims issued a decision regarding liability, but not the amount of compensation, for the Constitutional takings claim. The Court held that the federal government has authority to protect winter-run Chinook salmon and Delta smelt under ESA, but that it must pay the costs of this protection to water users who would have received that water from the SWP. The trial to determine the amount of compensation to be paid was held in July 2002. The Court's final decision is expected in late 2003 or early 2004.

Operations

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| Bay Delta Standards, <i>Staff</i> | 3 |
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Bay Delta Standards

California Department of Water Resources - Division of Operations and Maintenance Operations Control Office

The standards listed below have been implemented under the State Water Resources Control Board Decision-1641.

Bay-Delta Standards **DRAFT** Contained in D-1641

| CRITERIA | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|--|-----------------|----------------|--------------------------------|------------------------------------|-------------------------|-----------------|----------------|-----|---------------------|-------------------|-----------------------------|-----|
| FLOW/OPERATIONAL | | | | | | | | | | | | |
| • Fish and Wildlife | | | | | | | | | | | | |
| SWP/CVP Export Limits | | | | | 1,500cfs ^[1] | | | | | | | |
| Export/Inflow Ratio ^[2] | 65% | | | 35% of Delta Inflow ^[3] | | | | | 65% of Delta Inflow | | | |
| Minimum Delta Outflow | ^[4] | | | | | | | | 3,000 - 8,000 cfs | | | |
| Habitat Protection Outflow | | | | 7,100 - 29,200 cfs | | | | | | | | |
| Salinity Starting Condition ^[5] | | ^[6] | | | | | | | | | | |
| River Flows: | | | | | | | | | | | | |
| @ Rio Vista | | | | | | | | | | 3,000 - 4,500 cfs | | |
| @ Vernalis - Base | | | 710 - 3,420 cfs ^[8] | | | | ^[8] | | | | | |
| - Pulse | | | | | ^[9] | | | | | +2±TA | | |
| Delta Cross Channel Gates | ^[10] | | | Closed | | ^[11] | | | | | Conditional ^[12] | |

WATER QUALITY STANDARDS

| | | | | | | | | | | | | |
|--|---------|--------|--|--|------------------|--|--|--|--|--------|-----------------|------|
| • Municipal and Industrial | | | | | | | | | | | | |
| All Export Locations | | | | | | | | | | | | |
| Contra Costa Canal | | | | | | | | | | | | |
| • Agriculture | | | | | | | | | | | | |
| Western/Interior Delta | | | | | | | | | | | | |
| Southern Delta ^[14] | | 1.0 mS | | | | | | | | 1.0 mS | | |
| • Fish and Wildlife | | | | | | | | | | | | |
| San Joaquin River Salinity ^[15] | | | | | 14-day avg, 0.44 | | | | | | | |
| Suisun Marsh Salinity ^[16] | 12.5 EC | 8.0 EC | | | 11.0 EC | | | | | 19.0 | ^[17] | 15.5 |

1)

Maximum 3-day running average of combined export rate (cfs) which includes Tracy Pumping Plant and Clifton Court Forebay Inflow less Byron-Bethany

| Year Type | All |
|----------------|--|
| Apr15 - May15* | The greater of 1,500 or 100% of 3-day avg. Vernalis flow |

* This time period may need to be adjusted to coincide with fish migration. Maximum export rate may be varied by CalFed Op's group.

2)

The maximum percentage of average Delta inflow (use 3-day average for balanced conditions with storage withdrawal, otherwise use 14-day average) diverted at Clifton Court Forebay (excluding Byron-Bethany pumping) and Tracy Pumping Plant using a 3-day average. (These percentages may be adjusted

3)

The maximum percent Delta inflow diverted for Feb may vary depending on the January 8RI.

| Jan 8RI | Feb exp. limit |
|-----------------------|----------------|
| ≤ 1.0 MAF | 45% |
| between 1.0 & 1.5 MAF | 35%-45% |
| > 1.5 MAF | 35% |

4)

Minimum monthly average Delta outflow (cfs). If monthly standard ≤ 5,000 cfs, then the 7-day average must be within 1,000 cfs of standard; if monthly standard > 5,000 cfs, then the 7-day average must be ≥ 80% of standard.

| Year Type | All | W | AIH | BH | D | C |
|-----------|--------|-------|-------|-------|-------|-------|
| Jan | 4,500* | | | | | |
| Jul | | 8,000 | 8,000 | 6,500 | 5,000 | 4,000 |
| Aug | | 4,000 | 4,000 | 4,000 | 3,500 | 3,000 |
| Sep | 3,000 | | | | | |
| Oct | | 4,000 | 4,000 | 4,000 | 4,000 | 3,000 |
| Nov-Dec | | 4,500 | 4,500 | 4,500 | 4,500 | 3,500 |

* Increase to 6,000 if the Dec 8RI is greater than 800 TAF

5)

Minimum 3-day running average of daily Delta outflow of 7,100 cfs OR: either the daily average or 14-day running average EC at Collinsville is less than 2.64 mmhos/cm (This standard for March may be relaxed if the Feb 8RI is less than 500 TAF. The standard does not apply in May and June if the May estimate of the SRIIS < 8.1 MAF at the 90% exceedence level in which case a minimum 14-day running average flow of 4,000 cfs is required.) For additional Delta outflow objectives, see **TABLE A**.

6)

February starting salinity: If Jan 8RI > 900 TAF, then the daily or 14-day running average EC @ Collinsville must be ≤ 2.64 mmhos/cm for at least one day between Feb 1-14. If Jan 8RI is between 650 TAF and 900 TAF, then the CalFed Op's group will determine if this requirement must be met.

7)

Rio Vista minimum monthly average flow rate in cfs (the 7-day running average shall not be less than 1,000 below the monthly objective).

| Year Type | All | W | AN | BN | D | C |
|-----------|-------|-------|-------|-------|-------|-------|
| Sep | 3,000 | | | | | |
| Oct | | 4,000 | 4,000 | 4,000 | 4,000 | 3,000 |
| Nov-Dec | | 4,500 | 4,500 | 4,500 | 4,500 | 3,500 |

8)

BASE Vernalis minimum monthly average flow rate in cfs (the 7-day running average shall not be less than 20% below the objective). Take the higher objective if X2 is required to be west of Chipps Island.

| Year Type | All | W | AN | BN | D | C |
|-------------------------------|-----|-------------------|-------------------|-------------------|-------------------|-----------------|
| Feb-Apr14 and May16-Jun | | 2,130 or 3,420 | 2,130 or 3,420 | 1,420 or 2,280 | 1,420 or 2,280 | 710 or 1,140 |

9)

PULSE Vernalis minimum monthly average flow rate in cfs. Take the higher objective if X2 is required to be west of Chipps Island.

| Year Type | All | W | AN | BN | D | C |
|------------------|--------|-------------------|-------------------|-------------------|-------------------|-------------------|
| Apr15 - May15 | | 7,330 or 8,620 | 5,730 or 7,020 | 4,620 or 5,480 | 4,020 or 4,880 | 3,110 or 3,540 |
| Oct | 1,000* | | | | | |

* Up to an additional 28 TAF pulse/attraction flow to bring flows up to a monthly average of 2,000 cfs except for a critical year following a critical year. Time period based on real-time monitoring and determined by CalFed Op's group.

10)

For the Nov-Jan period, Delta Cross Channel gates may be closed for up to a total of 45 days.

11)

For the May 21-June 15 period, close Delta Cross Channel gates for a total of 14 days per CALFED Op's group. During the period the Delta cross channel gates may close 4 consecutive days each week, excluding weekends.

12)

Minimum # of days that the mean daily chlorides ≤ 150 mg/l must be provided in intervals of not less than 2 weeks duration. Standard applies at Contra Costa Canal Intake or Antioch Water Works Intake.

| Year Type | W | AN | BN | D | C |
|-----------|-----|-----|-----|-----|-----|
| # Days | 240 | 190 | 175 | 165 | 155 |

13)

The maximum 14-day running average of mean daily EC (mmhos/cm) depends on water year type.

| Year Type | WESTERN DELTA | | | | INTERIOR DELTA | | | |
|------------|------------------------------------|--------------------------------------|------------------------------------|--------------------------------------|------------------------------------|--------------------------------------|------------------------------------|--------------------------------------|
| | Sac River @ Emmaton | | SJR @ Jersey Point | | Mokelumne R @ Terminous | | SJR @ San Andreas | |
| | 0.45 EC from April 1 to date shown | EC value from date shown to Aug 15 * | 0.45 EC from April 1 to date shown | EC value from date shown to Aug 15 * | 0.45 EC from April 1 to date shown | EC value from date shown to Aug 15 * | 0.45 EC from April 1 to date shown | EC value from date shown to Aug 15 * |
| W | Aug 15 | | Aug 15 | | Aug 15 | | Aug 15 | |
| All | Jul 1 | 0.63 | Aug 15 | | Aug 15 | | Aug 15 | |
| BH | Jun 20 | 1.14 | Jun 20 | 0.74 | Aug 15 | | Aug 15 | |
| D | Jun 15 | 1.67 | Jun 15 | 1.35 | Aug 15 | | Jun 25 | 0.58 |
| C | | 2.78 | | 2.20 | | 0.54 | | 0.87 |

*When no date is shown, EC limit continues from April 1.

14)

As per D-1641, for San Joaquin River at Vernalis: however, the April through August maximum 30-day running average EC for San Joaquin River at Brandt Bridge, Old River near Middle River, and Old River at Tracy Road Bridge shall be 1.0 EC until April 1, 2005 when the value will be 0.7 EC.

15)

Compliance will be determined between Jersey Point & Prisoners Point.

Does not apply in critical years or in May when the May 90% forecast of SRI \leq 8.1 MAF.

During deficiency period, the maximum monthly average mhtEC at Western Suisun Marsh stations as per SMPA is:

| Month | mhtEC |
|----------------|-------|
| Oct | 19.0 |
| Nov | 16.5 |
| Dec-Mar | 15.6 |
| Apr | 14.0 |
| May | 12.5 |

In November, maximum monthly average mhtEC = 16.5 for Western Marsh stations and maximum monthly average mhtEC = 15.5 for Eastern Marsh stations in all periods types.

TABLE A

Number of Days When Max. Daily Average Electrical Conductivity of 2.64 mmhos/cm Must Be Maintained. (This can also be met with a maximum 14-day running average EC of 2.64 mmhos/cm, or 3-day running average Delta outflows of 11,400 cfs and 29,200 cfs, respectively.) Port Chicago Standard is triggered only when the 14-day average EC for the last day of the previous month is 2.64 mmhos/cm or less. PMI is previous month's 8RI. If salinity/flow objectives are met for a greater number of days than required for any month, the excess days shall be applied towards the following month's requirement. The number of day's for values of the PMI between those specified below shall be determined by linear interpolation.

| PMI (TAF) | Chippis Island (Chippis Island Station D10) | | | | |
|--------------|--|-----|-----|-----|-----|
| | FEB | MAR | APR | MAY | JUN |
| ≤ 500 | 0 | 0 | 0 | 0 | 0 |
| 750 | 0 | 0 | 0 | 0 | 0 |
| 1000 | 28* | 12 | 2 | 0 | 0 |
| 1250 | 28 | 31 | 6 | 0 | 0 |
| 1500 | 28 | 31 | 13 | 0 | 0 |
| 1750 | 28 | 31 | 20 | 0 | 0 |
| 2000 | 28 | 31 | 25 | 1 | 0 |
| 2250 | 28 | 31 | 27 | 3 | 0 |
| 2500 | 28 | 31 | 29 | 11 | 1 |
| 2750 | 28 | 31 | 29 | 20 | 2 |
| 3000 | 28 | 31 | 30 | 27 | 4 |
| 3250 | 28 | 31 | 30 | 29 | 8 |
| 3500 | 28 | 31 | 30 | 30 | 13 |
| 3750 | 28 | 31 | 30 | 31 | 18 |
| 4000 | 28 | 31 | 30 | 31 | 23 |
| 4250 | 28 | 31 | 30 | 31 | 25 |
| 4500 | 28 | 31 | 30 | 31 | 27 |
| 4750 | 28 | 31 | 30 | 31 | 28 |
| 5000 | 28 | 31 | 30 | 31 | 29 |
| 5250 | 28 | 31 | 30 | 31 | 29 |
| ≥ 5500 | 28 | 31 | 30 | 31 | 30 |

*When 800 TAF < PMI < 1000 TAF, the number of days is determined by linear interpolation between 0 and 28 days.

| PMI (TAF) | Port Chicago (continuous recorder at Port Chicago) | | | | |
|--------------|---|-----|-----|-----|-----|
| | FEB | MAR | APR | MAY | JUN |
| 0 | 0 | 0 | 0 | 0 | 0 |
| 250 | 1 | 0 | 0 | 0 | 0 |
| 500 | 4 | 1 | 0 | 0 | 0 |
| 750 | 8 | 2 | 0 | 0 | 0 |
| 1000 | 12 | 4 | 0 | 0 | 0 |
| 1250 | 15 | 6 | 1 | 0 | 0 |
| 1500 | 18 | 9 | 1 | 0 | 0 |
| 1750 | 20 | 12 | 2 | 0 | 0 |
| 2000 | 21 | 15 | 4 | 0 | 0 |
| 2250 | 22 | 17 | 5 | 1 | 0 |
| 2500 | 23 | 19 | 8 | 1 | 0 |
| 2750 | 24 | 21 | 10 | 2 | 0 |
| 3000 | 25 | 23 | 12 | 4 | 0 |
| 3250 | 25 | 24 | 14 | 6 | 0 |
| 3500 | 25 | 25 | 16 | 9 | 0 |
| 3750 | 26 | 26 | 18 | 12 | 0 |
| 4000 | 26 | 27 | 20 | 15 | 0 |
| 4250 | 26 | 27 | 21 | 18 | 1 |
| 4500 | 26 | 28 | 23 | 21 | 2 |
| 4750 | 27 | 28 | 24 | 23 | 3 |
| 5000 | 27 | 28 | 25 | 25 | 4 |
| 5250 | 27 | 29 | 25 | 26 | 6 |
| 5500 | 27 | 29 | 26 | 28 | 9 |
| 5750 | 27 | 29 | 27 | 28 | 13 |
| 6000 | 27 | 29 | 27 | 29 | 16 |
| 6250 | 27 | 30 | 27 | 29 | 19 |
| 6500 | 27 | 30 | 28 | 30 | 22 |
| 6750 | 27 | 30 | 28 | 30 | 24 |
| 7000 | 27 | 30 | 28 | 30 | 26 |
| 7250 | 27 | 30 | 28 | 30 | 27 |
| 7500 | 27 | 30 | 29 | 30 | 28 |
| 7750 | 27 | 30 | 29 | 31 | 28 |
| 8000 | 27 | 30 | 29 | 31 | 29 |
| 8250 | 28 | 30 | 29 | 31 | 29 |
| 8500 | 28 | 30 | 29 | 31 | 29 |
| 8750 | 28 | 30 | 29 | 31 | 30 |
| 9000 | 28 | 30 | 29 | 31 | 30 |
| 9250 | 28 | 30 | 29 | 31 | 30 |
| 9500 | 28 | 31 | 29 | 31 | 30 |
| 9750 | 28 | 31 | 29 | 31 | 30 |
| 10000 | 28 | 31 | 30 | 31 | 30 |
| > 10000 | 28 | 31 | 30 | 31 | 30 |

Planning

| | |
|---|----|
| Basic Strategic Planning, <i>Department of Finance Staff</i> | 3 |
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Basic Strategic Planning From California Department of Finance

Strategic planning asks and answers four basic questions. The process of addressing these questions produces responses which become the Strategic Plan. The components of a recommended strategic planning process that correspond with these questions are as follows:

Where Are We Now?

Before an agency can develop a plan for a change, it must first determine where it currently stands and what opportunities for change exist. Strategic planning is supported by:

External/Internal Assessment

An analysis and evaluation of key internal and key external data and factors that influence the success of an agency in achieving its mission and goals. Two components of this assessment are:

Situation Inventory

An assessment of an agency's position, performance, problems, and potential; in other words, its strengths and weaknesses.

Environmental Scan

An analysis of key external elements or forces, including the stakeholder analysis, that affect the environment in which an agency functions. This is commonly referred to as the opportunities of and threats to the agency. In developing a strategic plan, an agency should consult with the Legislature and solicit and consider the views and suggestions of entities, such as customers and other stakeholders, potentially affected by or interested in the plan.

Mission

The agency's unique reason for existence; the overarching goal for the agency's existence, usually contained within a formal statement of purpose. In addition, mission statements can be developed at the program and subprogram level.

Principles

The agency's core values and philosophies describing how the agency conducts itself in carrying out its mission.

Where Do We Want to Be?

Strategic planning identifies:

Vision

A compelling, conceptual, vivid image of the desired future.

Goals

The desired end result, generally after three or more years.

Objectives

Specific and measurable targets for accomplishment of a goal.

How Do We Get There?

Strategic planning develops:

Action Plan

A detailed description of the key strategies used to implement each objective.

How Do We Measure Our Progress?

Strategic planning builds in:

Performance Measures

The methods used to measure results and ensure accountability.

Monitoring and Tracking Systems

The systems to monitor progress, compile management information and keep the plan on track.

Finally, strategic planning guides:

Resource Allocation

The determination and allotment of assets or resources, including those for capital outlay, necessary to carry out strategies and achieve objectives, within a priority framework.

Customer and Stake Holders Survey for Water Plan Update 2003

STATE OF CALIFORNIA – THE RESOURCES AGENCY

GRAY DAVIS, *Governor*

DEPARTMENT OF WATER RESOURCES

1416 NINTH STREET, P.O. BOX 942836
SACRAMENTO, CA 94236-0001



We need your input. The Department of Water Resources (DWR) is now preparing the *California Water Plan - Update 2003* for release at the end of 2003. We are committed to a collaborative, stakeholder-driven approach for preparing *Update 2003*, with broad public participation. That is where you fit in. We want to know how we can make the Water Plan more useful to you. That is why we developed an Internet survey for customers and stakeholders of *Update 2003*.

State law requires DWR to update *the California Water Plan*, also known as Bulletin 160, every five years. *The California Water Plan* is many things to many people. It provides a framework for water managers, legislators, and the public to consider options and make decisions regarding California's water future. The Plan presents basic information on California's water resources, including water supply evaluations and assessments of agricultural, urban, and environmental water uses. The Plan quantifies the reliability of water supplies to its various uses. It also identifies and evaluates existing and proposed statewide demand management and supply augmentation programs and projects to address the State's future water needs.

The survey takes only about 10 minutes to complete. To take the survey, just click on:
www.tec-web.com/cawaterplansurvey/Login.asp

When it asks for your username enter your first and last name, and for the password enter "*cawater01*".

Thank you in advance for helping make *Update 2003* a more useful resource.

Sincerely,

Jonas Minton, Deputy Director
California Department of Water Resources

Customer Survey

See the previous page to read the letter from DWR's Deputy Director, Jonas Minton, inviting you to take the survey.

What is the purpose of the survey?

The purpose is three-fold:

- Marketing - to increase awareness and acceptance (e.g., expanding our user base, increasing credibility through stakeholder buy-in)
- User Needs Assessment - to answer, "How can the Water Plan best assist existing and potential Water Plan users with their missions?"
- Evaluation – to answer, "What can we do better and how?"
- What is the main question we are trying to answer?

How can we make the Plan more widely read, understood and useful?

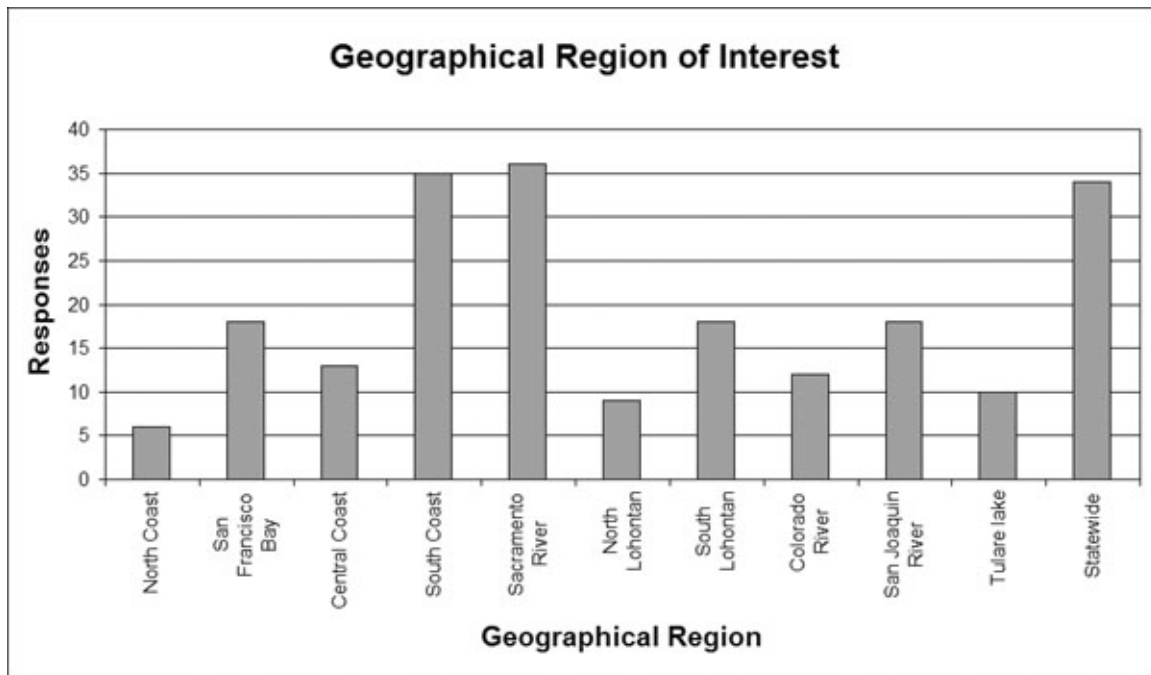
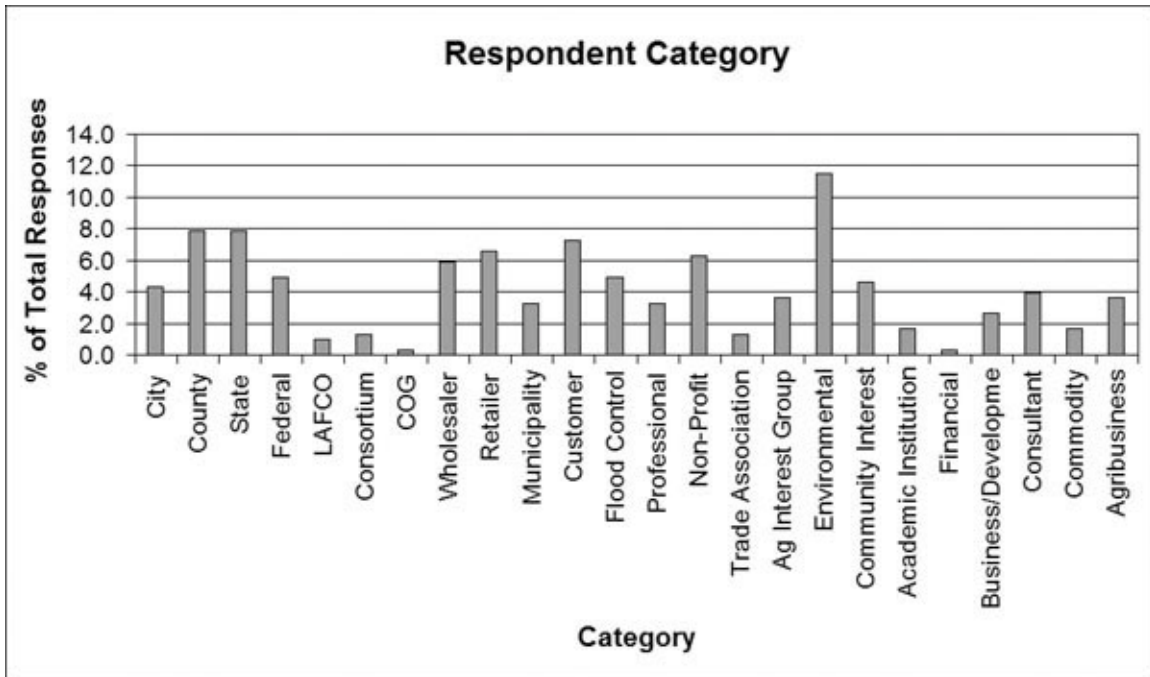
Who is the target audience?

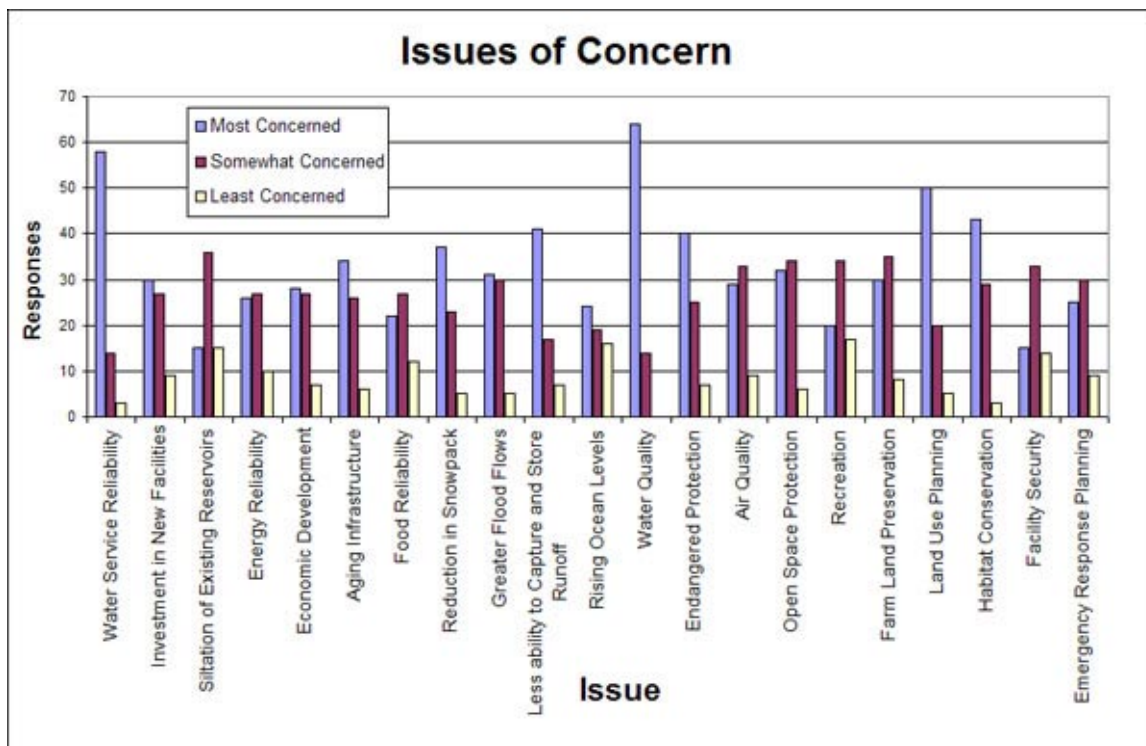
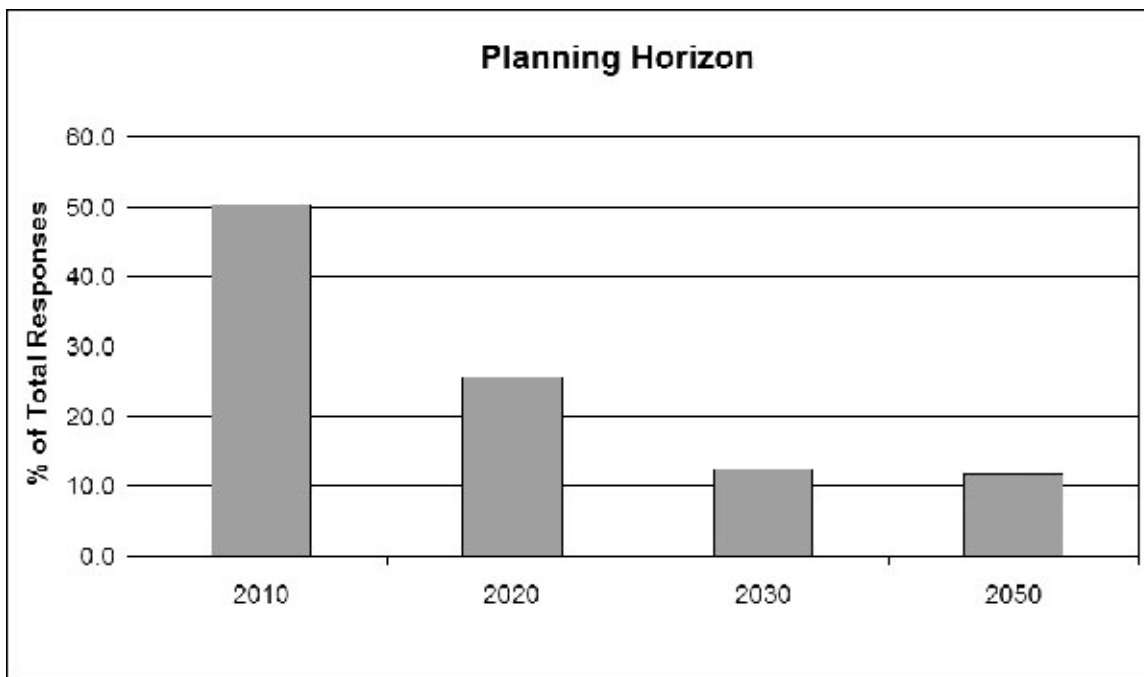
The target audience is very diverse as we are trying to reach existing as well as potential new users. This expands the audience of government, private and non-profit entities to include land use planners, natural resources planners, environmental and social advocacy groups, business sectors (e.g., agricultural, real estate, financing), professional associations, academic institutions, water planners, wholesalers and retailers, and similar individuals and groups.

How will we use the information?

Two key deliverables resulting from this survey will be: (1) a summary of user suggestions; and (2) correlations intended to tell us which elements of the plan are most and least used/useful and to whom. We will capture all of these suggestions and correlations and share them with the public Advisory Committee for Update 2003. Based on their input and DWR resources, suggestions and insights will either be incorporated into Update 2003 or will be available for use by the Update 2008 team.

Customer Survey Graphical Results





Future Scenarios and Responses

Introduction

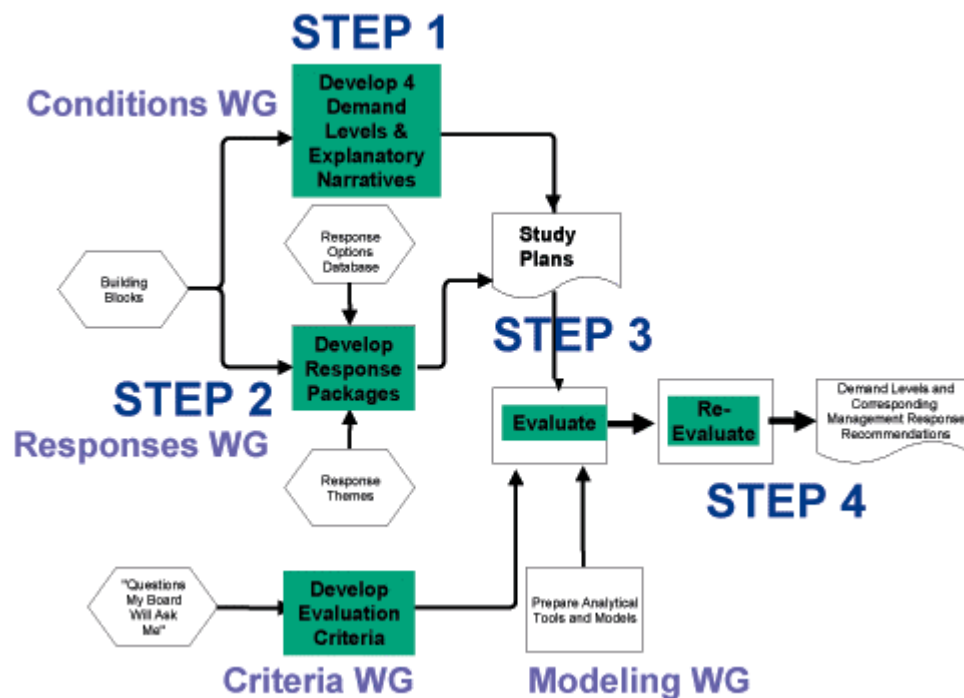
The concept of scenario planning is like a decision tree analysis that outlines different actions or responses based on different plausible futures. Some actions would be common and implemented regardless of the scenario, others actions will be taken in response to specific conditions. Scenarios are neither positive nor negative.

These plausible “futures” are differentiated by important assumptions about uncertainties in water resource conditions that could significantly affect responses or actions taken to control the vulnerability to the assumption, such as using no or low regret strategies, or to better prepare for changes in future conditions, such as taking actions that would respond to incorrect assumptions about future water needs or future changes in climate.

The development of different response packages may tend to favor or shape actions toward a desirable future condition within a plausible future scenario. It is in this area of no-regret actions where stakeholders can identify areas of agreement and where short-term measures can be implemented. In the long-term time frame, where uncertainties about future assumptions increase, it is important to monitor and plan for the likelihood that in the event future conditions are worse than assumed, there is sufficient time to plan and implement adequate response measures for the changed conditions.

An important element of scenario planning for the Water Plan is that as the State continues to grow, the updates of the Water Plan will need to re-evaluate strategies based on revised plausible futures that incorporate increased certainty about future conditions or changes in water policies.

The steps in the planning process for the update of the Water Plan can be summarized in the following flow diagram:



Update 2003 considers resource management strategies (discussed in Chapter 5) to study in conjunction with the four plausible future scenarios. A group of strategies could be implemented together or “packaged” to manage possible future conditions. The effectiveness of the strategies and packages could be evaluated for each of the four scenarios using a comprehensive list of evaluation criteria comprising the three “E’s”: economics, environment and equity and institutional flexibility and technical feasibility.

This qualitative analysis would inform the quantitative work in Phases 2 (year 2004) and Phase 3 (year 2005) of the Water Plan. However, these strategies and response packages do not define the Water Plan’s quantitative effort. The purpose of developing the scenarios and crafting responses is to think creatively about how to apply the Water Plan’s tool kit, represented in Chapter 5’s strategy descriptions given the recommendations for reducing uncertainties (Chapter 3) and integrated resource planning (Chapter 4).

Study Plan Evaluation Process (Phases 2 & 3)

Step 1 - Develop Demand Levels from Future Scenarios

- Develop Use Levels
- Derive Demand Curves

Step 2 - Develop Detailed Response Packages

- Economic Efficiency and Other Criterion
- Themed Packages (from Mgmt. Responses Work Group)

Step 3 - Evaluate Response Performance

- Data and Analytical Tools
- Economic Criteria:
 - Demand Reduction Cost
 - Supply Augmentation Cost
 - Cost of Forgone Use
- Other Criteria (from Criteria Work Group)

Step 4 - Re-Evaluate Response Packages to Improve Performance by way of Evaluation Criteria

Proposed RAND Contribution to the 2003 California State Water Plan

Developing scenarios is a good way to recognize how uncertainties may impact the future and to begin devising policies that will perform well under several different futures. The approach of evaluating several scenarios and planning accordingly, however, may still leave California vulnerable to surprise. Given the large number of uncertain factors driving the future, no small set of scenarios could possibly span the entire range of plausible futures. Furthermore, scenario evaluation alone will not be able to rank policies for decision makers or resolve the numerous conflicting concerns and desires of various stakeholder groups.

Robust decisionmaking methods are available to complement scenario analysis and identify policy strategies that are truly robust – those that will perform reasonably well over a very wide range of plausible futures. These methods also are designed to foster collaboration and consensus, features that will prove critical to California water resource planning. The performance of policies can be evaluated across multiple dimensions such as cost, environmental impact, and water delivery reliability. Additionally, robust solutions are often adaptive and change over time. Techniques for robust decisionmaking have been developed over the past decade and are now being actively applied to other difficult long-term problems such as global sustainability, science and technology planning, military procurement, and long-range financial planning for the California public university systems. DWR will be evaluating these techniques in conjunction with other modeling approaches during Phases 2 and 3 to improve the ability to devise appropriate policies that will be successful under any plausible future.

Future Scenarios

DWR and the Advisory Committee developed three scenarios of plausible events that could shape future water use by 2030. The scenarios describe the plausible conditions that *could happen*. The scenarios concentrate on statewide implications of regional shifts. The complement to the scenarios is response packages. The responses describe what options could be taken to manage these possible future conditions. The effectiveness of response packages can be evaluated for each scenario using the comprehensive evaluation criteria.

Peter Schwartz, a pioneer in the field of scenario planning, explains:

In a scenario process, managers invent and then consider, in depth, several varied stories of equally plausible futures. The stories are carefully researched, full of relevant detail, oriented toward real-life decisions, and designed (one hopes) to bring forward surprises and unexpected leaps of understanding. Together, the scenarios comprise a tool for ordering one's perceptions. The point is not to "pick one preferred future," and hope for it to come to pass. Nor is the point to find the most probably future and adapt to it or "bet the company" on it. Rather, the point is to make strategic decisions that will be sound for all plausible futures. No matter what future takes place, you are much more likely to be ready for it—and influential in it—if you have thought seriously about scenarios.¹

A scenario-building process for comprehensive plan-making can identify plausible futures for a range of uncertainties. Packages of management strategies (from Volume 3) can be tested over the plausible futures to measure their effectiveness in reaching desired futures or outcomes and identifying no-regrets strategies. Scenarios for the Water Plan include:

¹ Schwartz, Peter, *The Art of the Long View*, Currency, 1991. p. xiv-xiv

- Scenario 1—Current Trends: Continue with no big surprises.
- Scenario 2—Resource Sustainability: California is more efficient in 2030 water use than today while growing its economy and restoring its environment.
- Scenario 3—Resource Intensive: California is highly productive, respectful of the environment, yet less efficient in 2030 water use than today.

Key Factors

DWR have defined these factors as key drivers affecting water management as part of a larger list of factors and is shown in the following Table. This table was used as a stepping stone in developing the narratives for the scenarios. The Advisory Committee recommended that the scenarios highlight the following key factors due to their strategic role in affecting water use, supply, and management. Although some estimated ranges are presented for these factors, the discussion is meant to be largely qualitative.

Total Population: The statewide total population projection regardless of geographical distribution

Population Density: The average number of people per square mile for a planning area.

Per Capita Income: The average annual income from all sources per person for a planning area.

Total Commercial Activity: The amount of commercial activity (e.g. employment, productivity, commercial land use, etc) that occurs in a given study area. This factor is a driver of (and indicator for) commercial water use and includes institutional water use (government offices, schools, etc).

Commercial Activity Mix: The mix of high and low water using commercial activity. Note that Commercial Activity is broken into two factors: Total Activity and Activity Mix. The latter factor allows designation of the type of commercial activity that is occurring.

Total Industrial Activity: The total amount of industrial activity (e.g. employment, productivity, industrial land use, etc) that occurs in a given study area. This factor is a driver of (and indicator for) industrial water use.

Industrial Activity Mix: The mix of high and low water using industrial activity. Note that Industrial Activity is broken into two factors: Total Industrial Activity and Industrial Activity Mix. The latter factor allows designation of the type of industry that is occurring. This is necessary to account for the large variation in water demands by industry type.

Irrigated Land Area: The land area under irrigation in a study area.

Crop Acreage: The number of irrigated crop acres (by crop category) planted in a study area during a given year; this number includes multiple cropping.

Crop Unit Water Use: Changes in the volume of water used per acre of cropped area due to changes in crop type. This can be a function of evapotranspiration rates and cultural practices, but NOT use efficiency. Ag use efficiency is captured under its own distinct factor.

Environmental Water Flow: Water flowing to the environment is not an indicator of environmental conditions. **Flow Based:** The amount of water dedicated to in stream uses and aquatic habitat. Flow based is estimated by (a) Delta outflow, (b) in stream flow requirements, (c) Wild and Scenic River flows (d) Environmental Water Account asset allocations, (e) Anadromous Fish Restoration Program flows, and (f) Ecosystem Restoration Program flow targets. **Land Based:** The amount of water used by managed wetlands and native vegetation. The amount should be estimated by the amount of water used by managed wetlands and native vegetation including riparian water use, however, native vegetation water use is not quantifiable at this time.

Naturally Occurring Conservation: The amount of background conservation occurring independent of the BMP and EWMP programs.

Each scenario aims to represent a plausible 2030. This scenario will be paired with one or more response packages, which describe actions that could be implemented to manage these possible future conditions. The effectiveness of each response package paired with the scenario can be evaluated using the evaluation criteria to look at the effects on the environmental, economics, and equity issues.

Factors Affecting Regional and Statewide Water Use and Supplies¹

Four Possible Future Scenarios for 2030

| FACTOR | SCENARIO 1 CURRENT TRENDS LOW | SCENARIO 2 CURRENT TRENDS HIGH | SCENARIO 3 HIGH URBAN PRODUCTIVITY, HEALTHY AG SECTOR, HIGH ENVIRONMENTAL PROTECTION, LOWER WATER USE AND HIGH EFFICIENCY | SCENARIO 4 HIGH URBAN PRODUCTIVITY, HEALTHY AG SECTOR, HIGH ENVIRONMENTAL PROTECTION, HIGHER WATER USE AND LOWER EFFICIENCY |
|---|--|--|--|---|
| Total Population | DOF | DOF | DOF | Higher than DOF |
| Population Density | DOF | DOF | Higher than DOF | Lower than DOF |
| Population Distribution | DOF | DOF | DOF | Higher Inland & Southern; Lower Coastal & Northern |
| Commercial Activity | Current Trend—Low range | Current Trend—High Range | Increase in Trend | Increase in Trend (Same as Scenario 3) |
| Commercial Activity Mix | Current Trend—Low range | Current Trend—High Range | Decrease in High Water Using Activities | Increase in High Water Using Activities |
| Total Industrial Activity | Current Trend—Low range | Current Trend—High Range | Increase in Trend | Increase in Trend (Same as Scenario 3) |
| Industrial Activity Mix | Current Trend—Low range | Current Trend—High Range | Decrease in High Water Using Activities | Increase in High Water Using Industries |
| Total Crop Area (Includes Multiple Cropping) | Current Trend—Low range | Current Trend—High Range | Level Out at Current Crop Area | Level Out at Current Crop Area |
| Crop Unit Water Use | Current Trend—Low range | Current Trend—High Range | Decrease in Crop Unit Water Use | Increase in Crop Unit Water Use |
| Environmental Water-Flow Based | Current Trend - Low Objectives | Current Trend - High Objectives | High Environmental Protection | High Environmental Protection |
| Environmental Water-Land Based | Current Trend - Low Objectives | Current Trend - High Objectives | High Environmental Protection | High Environmental Protection |
| Naturally Occurring Conservation ² | NOC Trend in MOUs | NOC Trend in MOUs | Higher than NOC Trend in MOUs | Lower Than NOC Trend in MOUs |
| Urban Water Use Efficiency | All Cost Effective BMP's in Existing MOU's Implemented by Current Signatories (present commitments) | All Cost Effective BMP's in Existing MOU's Implemented by Current Signatories (present commitments) | All Cost Effective BMP's in Existing MOU's Implemented by Current Signatories (present commitments) | All Cost Effective BMP's in Existing MOU's Implemented by Current Signatories (present commitments) |
| Ag Water Use Efficiency | All Cost Effective EWMP's in Existing MOU's Implemented by Current Signatories (present commitments) | All Cost Effective EWMP's in Existing MOU's Implemented by Current Signatories (present commitments) | All Cost Effective EWMP's in Existing MOU's Implemented by Current Signatories (present commitments) | All Cost Effective EWMP's in Existing MOU's Implemented by Current Signatories (present commitments) |
| Per Capita Income | Current Trends | Current Trends | Current Trends | Current Trends |
| Seasonal/Permanent Crop Mix | Current Trends | Current Trends | Current Trends | Current Trends |
| Irrigated Land Retirement | Currently Planned | Currently Planned | Currently Planned | Currently Planned |
| Hydrology | Essentially a Repeat of History | Essentially a Repeat of History | Essentially a Repeat of History | Essentially a Repeat of History |
| Climate Change | Essentially a Repeat of History | Essentially a Repeat of History | Essentially a Repeat of History | Essentially a Repeat of History |
| Colorado River Supply | Equal to 4.4 Plan | Equal to 4.4 Plan | Equal to 4.4 Plan | Equal to 4.4 Plan |
| Existing Inter-Regional Import Projects | Current Conditions | Current Conditions | Current Conditions | Current Conditions |
| Flood Management | Current capacities, management practices and operations | Current capacities, management practices and operations | Current capacities, management practices and operations | Current capacities, management practices and operations |
| Energy Costs | As Projected From Current Trends | As Projected From Current Trends | As Projected From Current Trends | As Projected From Current Trends |
| Drinking Water Standards | Current and Planned | Current and Planned | Current and Planned | Current and Planned |
| Ag Discharge Requirements | Current and Planned | Current and Planned | Current and Planned | Current and Planned |
| Urban Runoff Mgmt. | Current Level of Use | Current Level of Use | Current Level of Use | Current Level of Use |
| Recreation | Present Demand Trends Continued | Present Demand Trends Continued | Present Demand Trends Continued | Present Demand Trends Continued |
| Desalting | Current Level + Permitted/Financed | Current Level + Permitted/Financed | Current Level + Permitted/Financed | Current Level + Permitted/Financed |
| Recycled Water | Current Level + Permitted/Financed | Current Level + Permitted/Financed | Current Level + Permitted/Financed | Current Level + Permitted/Financed |
| Water Transfers Within Regions | Currently Approved Transfers | Currently Approved Transfers | Currently Approved Transfers | Currently Approved Transfers |
| Water Transfers Between Regions | Currently Approved Transfers | Currently Approved Transfers | Currently Approved Transfers | Currently Approved Transfers |
| Integrated Ground & Surface Water Mgmt. | Current Level + Permitted/Financed | Current Level + Permitted/Financed | Current Level + Permitted/Financed | Current Level + Permitted/Financed |
| Groundwater Storage | Current Level + Permitted/Financed | Current Level + Permitted/Financed | Current Level + Permitted/Financed | Current Level + Permitted/Financed |
| Surface Water Storage | Current Level + Permitted/Financed | Current Level + Permitted/Financed | Current Level + Permitted/Financed | Current Level + Permitted/Financed |
| Conveyance Facilities | Current Level + Permitted/Financed | Current Level + Permitted/Financed | Current Level + Permitted/Financed | Current Level + Permitted/Financed |
| Rate Structure | Current Practices | Current Practices | Current Practices | Current Practices |
| Cost Recovery | Current Practices | Current Practices | Current Practices | Current Practices |

(1) Water supplies shown in Table 1 represent a baseline for the year 2030.

(2) Naturally Occurring Conservation is the amount of background conservation occurring independent of the BMP and EWMP programs.

Scenario 1: Current Trends

Population and Land Use

- Population in 2030 is what the California Department of Finance has projected – 51.75 million people.²
- Increasing population pressure in the valley and on the California coast. Most people are moving to cities with large populations and high percentages of growth in Fresno, Stockton, Modesto, Bakersfield and San Diego.
- Expanding metropolitan areas continue to affect the residents’ daily lives and agriculture.
- The cost of land in Southern California is growing—with shrinking availability.
- *Placeholder: add something on per capita income trends.*

Commercial and Industrial

- Industry has become more efficient in water use—driven to reduce costs in the face of competition. When possible, industries like concrete have moved to dry processing to eliminate water necessary to create its product—reducing costs.
- Businesses have been reducing water use over time because it is cost effective, primarily by replacing old or broken-down equipment with high efficiency machines.

Agriculture

- Irrigated agricultural land is about 7.75 million acres in 2030, a reduction of about 13 percent from 2000. Irrigated crop acreage, which includes multi-cropping, is about 8.52 million acres, a reduction of about 9.7 percent from 2000, and multi-cropping acreage increases by about 45 percent to 0.78 million acres from 2000
- Farmers are increasingly using sprinklers and drip irrigation, moving away from flooding and furrows. Farmers are able to turn irrigation on and off at will and decide exactly where to irrigate. Improved water management is modestly increasing water efficiency over 2000 levels. Irrigation techniques improve the uniform distribution of water to all plants, which is also contributing to an increase in plant size. Farmers produce more “crop per drop” through a variety of means, including changes in irrigation methods away from inefficient approaches, though more improvement is possible.
- A significant amount of the reduction in irrigated agricultural land is land with high quality soils. Any new land coming into production would be of poorer quality soils, decreasing some efficiency gains in applied water and yield per acre for those soils.
- Concerns about impacts to the local area from loss of farmland due to urbanization will continue to be addressed by local governments.

Environment

- Environmental flows would reach levels needed to meet the objectives of CALFED’s Ecosystem Restoration Program and the objectives in the Anadromous Fisheries Restoration Program. Water

² CA Department of Finance projects Total California Population to be 45,821,900 in 2020 and 58,731,000 in 2040. For purposes of this report, assume 2030 projection = [(2040 projection) + (2020 projection)]/2 or about 51.75 million

dedicated to wetlands would reach the “Level 4” supplemental water supplies for National Wildlife Refuges cited in CVPIA Sections 3405 and 3406(b).

- Some increase in the extent of managed wetlands designed to use in cleansing wastewater due to projects which use floodplains/wetlands for high flow management and ecosystem restoration programs.
- In some areas, continued loss of functioning floodplains due to the direct encroachment of urban development (flash floods and fast runoff).
- In urban areas, where new development has ended, continued regional and local efforts to restore functioning channels and floodplains.
- Environmental effects of new projects continue to be mitigated, to some degree, but do not fully offset losses of habitat (with species effects) and other watershed impacts.

Groundwater

- Increase in groundwater remediation and aquifer quality protection.

Efficiency

- Urban Best Management Practices (BMPs) are commonplace in most water agencies, including residential indoor and outdoor water use surveys and improvements; commercial, industrial, and institutional water use audits and retrofits, landscape irrigation audits and upgrades; district water system leak detection and repair programs; metering, commercial washing machine rebate programs, conservation pricing, waste water reduction ordinances, and public information and education programs.
- Urban landscape irrigation has decreased, where irrigation does occur, fewer chemicals are applied.
- Existing efficiency standards affecting washing machines, toilets, spray valves in restaurants continue to be implemented.

Water Quality

- Water quality best management practices are limited to local affordability; limited public funding assistance is available.
- Current quality impairments continue in many waterways, particularly those which are not directly linked as urban drinking water sources.
- Urban stormwater runoff regulations (NPDES) are implemented, and point source controls continue to be implemented.
- Runoff from irrigated lands and lands used for grazing and timber harvest, nonpoint sources of water pollution, has moderately reduced.
- Some decrease in flexibility to meet Delta water quality standards, due to reduced surplus inflow and greater reuse of water upstream. Standards are assumed to be met.
- Substantial improvement in the effectiveness and affordability of water filtration technologies.

Water Demand

- Placeholder: Add in estimates for consumptive and applied water use for this scenario.

Considerations³

- Placeholder: CALFED ROD assumptions
- Funding for agricultural and urban water use efficiency programs.
- Implementation of agricultural and urban efficiency measures is part of overall management strategy, not just a response to drought conditions.
- Continued resistance by some water agencies to implement agricultural and urban water use efficiency best management practices.
- Urban sprawl has consumed valuable farmland, open space and other natural resources and contributed to water pollution, extinction of species, and increased competition for limited water resources.
- Construction of vast amount of impervious surfaces, such as roads and rooftops lead to degradation of water quality by increasing surface runoff, altering regular stream flow and watershed hydrology, reducing groundwater recharge, and increasing stream sedimentation.
- Sprawl in metropolitan areas, and negative economic impacts in some areas (where known) have environmental justice implications.
- Assumptions about the management of drainage impaired lands will affect irrigated agriculture and have implications for water supply and water quality.

Scenario 2: Resource Sustainability

Population and Land Use

- Population in 2030 is what the California Department of Finance has projected – 51.75 million people.⁴
- Citizens live in mixed use developments with native vegetation requiring little or no irrigation. An increase in population density means infill in existing urban areas and less new urban land being developed. This compact development has reduced the need for impervious surfaces benefiting open space, reduced runoff and other related issues.
- The cost of land in Southern California is growing—with shrinking availability.
- *Placeholder: add something on per capita income trends.*

Commercial and Industrial

- The industrial, commercial and agricultural sectors are strong, balanced with high environmental protection.
- Urban areas have a high degree of commercial and industrial productivity.
- California is a global leader in all types of recycling technology.
- California has emerged as a leading industrial producer of environmental products and continued as a force in producing hardware for the technology industry.

³ Source: Chapter 5's management strategy narratives.

⁴ CA Department of Finance projects Total California Population to be 45,821,900 in 2020 and 58,731,006 in 2040. For purposes of this report, assume 2030 projection = [(2040 projection) + (2020 projection)]/2 or about 51.75 million.

- Industry has shifted from water-intensive processing to dry product assembly, reducing water use. Businesses have dramatically reduced demand. They have received incentives accelerating the move to machines with high efficiency water use to accomplish standard tasks.

Agriculture

- Crop acreage levels out at the current year 2000 level or 9.44 millions acres.⁵
- Even with increasing urban densities, there will still be urbanization of agricultural land. Any land acreage removed from agricultural must be replaced by a combination of new land coming into production or an increase in multi-cropping, to keep the crop acreage at its current level of 9.44 million acres. The amount of land acreage and multi-cropping acreage would be quantified in Phase II.
- A viable agricultural sector has sustained export levels and food production in keeping with market forces and trends.
- The social contract continues to keep food and fiber prices low.
- A healthy, efficient agricultural sector has no new irrigated acres, but is able to produce more per acre and decrease applied water per irrigated crop acre.
- Farmers use sprinklers and drip irrigation on nearly all appropriate crops and lands. Flooding and furrow irrigation are applied only where more efficient methods cannot be used.. Farmers turn irrigation on and off at will and decide exactly where to irrigate based on accurate information on soil moisture and climate conditions. Improved water management is increasing water efficiency. Irrigation techniques improve the uniform distribution of water to all plants, which is also contributing to yields.

Environment

- Instream flows are sufficient to meet the objectives of CALFED's Ecosystem Restoration Program and the Anadromous Fisheries Restoration Program. In addition, flow objectives have been developed for streams statewide and those objectives are being met.
- Environmental health regulations are fully enforced, especially for air and water quality.
- Projects are designed to achieve multiple benefits integrating ecosystem restoration with water supply reliability
- River floodplain protection and restoration is undertaken for high flow management, habitat benefits, groundwater recharge, and public recreation (where appropriate).
- New developments and infrastructure (such as roads) are designed to minimize impacts to the natural drainage patterns and water quality of watersheds and increase groundwater recharge using urban water retention measures.
- Management actions are oriented toward the sustainability, restoration and improvement of the natural infrastructure.
- Californians recognize the link between the environment and their economic health and personal well being. Wetlands and native vegetation flourish through high environmental protection. Water dedicated to in stream use and enhancing aquatic life is finally yielding increased populations. The sense of the State and its policy is to sustain this high degree of environmental protection.

Groundwater

- There is increased utilization of existing groundwater aquifers to meet water demand and for water storage due to local cooperative watershed and integrated resource plans.
- Groundwater basins have been remediated and aquifer quality protection is in place.

Economics and Water Pricing

- Water has a high degree of economic optimization (e.g. \$/drop) relative to existing economic activity types and water use efficiencies.
- Users are accustomed to paying more for water, especially in response to high levels of demand.
- The cost of investing in water use efficiency provides a return on investment.

Transfers and Conveyance

Infrastructure is built to permit local and regional water transfers in order to balance water supplies (but not large inter-regional transfers, especially those that must pump through the Delta)

Public Trust

- Water managers recognize public trust responsibilities to protect waters of the state for environmental, recreational, and aesthetic values.

Efficiency

- Naturally occurring conservation (NOC) trend is higher in the agricultural and urban sectors than under Scenario 1. Business and agriculture have recognized the benefits of conservation and implemented efficiency measures that go far beyond best management practices in place in 2000.
- Many houses are dual plumbed, enabling residents to use recycled water for appropriate uses.
- Municipal and agricultural best management practices become comprehensive, encouraging more water use efficiency improvements and practices to be developed.
- Native vegetation and other innovative landscaping techniques have greatly reduced residential demand for landscape irrigation.

Water Quality

- Water quality best management practices have been fully implemented.
- Implementation of urban stormwater runoff regulations (NPDES) and point source controls have exceeded anticipated levels.
- Runoff from irrigated lands and lands used for grazing and timber harvest, nonpoint sources of water pollution, has significantly reduced.
- Water quality in currently impaired lakes and rivers is substantially improved and clean waters are protected from degradation.

Water Demand

- Placeholder: Add in estimates for consumptive and applied water use for this scenario.

Considerations

- Placeholder: CALFED ROD assumptions
- Cost of implementation is a factor.

- Impact of climate change on hydrologies
- Funding for ag and urban water use efficiency programs
- Implementation of efficiency measures is part of overall management strategy, not just a response to drought conditions.
- Continued resistance by some water agencies to implement urban water use efficiency best management practices.
- Compact, mixed use development reduces water demand (landscaping) and minimizes pollution of surface and groundwater. Impacts to habitat, watershed functions, and groundwater recharge areas are reduced.

Scenario 3: Resource Intensive

Population and Land Use

- Population in 2030 is higher than what the California Department of Finance's projection of about 51.75 million.
- The population is dispersed regionally. Expanding urban areas are commonplace.
- Build-out for many cities and towns in Northern California and coastal regions hasn't been reached. More people live in the inland areas of the Central Valley and in the southern regions of California. Fresno, Stockton, Modesto, Bakersfield and San Diego have large populations and have experienced high percentages of growth.
- The population is more spread out resulting in more outdoor residential water use (e.g. larger residential lot size).
- The Central Valley is experiencing air and water quality problems due to the stress of the high population.
- People tend to drive individually long distances to the work place.
- Placeholder: add something on per capita income trends.

Commercial and Industrial

- The industrial, commercial and agricultural sectors are strong, balanced with existing environmental protection.
- Difficulty attracting clean, efficient industries has an impact on the state's attractiveness.
- California has become a global leader in recycling technology.
- California has emerged as a leading industrial producer of environmental products and continued as a force in producing hardware for the technology industry. California's leadership in high tech hardware places constraints on its water resources since this industry is a high water using industry that has not achieved advances in technology to limit its water use.
- Industry continues to rely on high water-using processes based on market conditions.

Agriculture

- Crop acreage levels out at the current year 2000 level or about 9.44 millions acres.⁶
- The healthy agricultural sector maintains past levels of food and fiber production. Low-density urban development expands onto prime farmland, but harvested acreage remains about the same due

to increased multi-cropping and new lands coming into production. The amount of land acreage and multi-cropping acreage would be quantified in Phase II.

- The annual volume of applied water per crop is high due to the changing nature of crops grown and the movement of agricultural production to lands with poor soil quality.
- There are no new long-term transfers of water from the agricultural sector to the cities.

Environment

(Note: The level at which these factors can be plausible under this scenario will need to be determined—May not be the same level as Scenario 2)

- To the extent possible, instream flows are sufficient to meet the objectives of CALFED's Ecosystem Restoration Program and the Anadromous Fisheries Restoration Program. In addition, flow objectives have been developed for streams statewide and those objectives are being met.
- Environmental health regulations are fully implemented, especially for air and water quality.
- Projects are designed to achieve multiple benefits integrating ecosystem restoration with water supply reliability
- River floodplain protection and restoration is undertaken for high flow management, habitat benefits, groundwater recharge, and public recreation (where appropriate).
- Californians recognize the link between the environment and their economic health and personal well being. Wetlands and native vegetation flourish through high environmental protection. Water dedicated to in stream use and enhancing aquatic life is finally yielding increased populations. The sense of the State and its policy is to sustain this high degree of environmental protection.

Groundwater

- Although some groundwater basins have been remediated and recharge protection is in place, groundwater overdraft is prevalent in the state and land subsidence occurs.

Economics and Water Pricing

- Water is used with a low degree of economic optimization (e.g. \$/drop) relative to the economic activity types and efficiencies.

Efficiency

- (Naturally occurring) conservation in the agricultural and commercial and industrial sectors is lower than the current trends.

Quality

Water quality best management practices have been fully implemented but not extended.

Implementation of urban stormwater runoff regulations (NPDES) and point source controls have reached but not exceeded anticipated levels.

Runoff from irrigated lands and lands used for grazing and timber harvest, nonpoint sources of water pollution, has significantly reduced.

Improvements in water quality in impaired lakes from existing regulations are becoming more difficult to achieve.

Water Demand

- Water planners and decision makers have to contend with high water use in every sector.

- Water use is less efficient than in Scenario 2.
- Placeholder: Add in estimates for consumptive and applied water use for this scenario.

Considerations

- Placeholder: CALFED ROD assumptions
- Water quality has become a major challenge due to the increased demands and expanding urban areas.
- Water conveyance requires a great deal of infrastructure improvement due to the dispersed population.
- Expanding urban areas have consumed valuable farmland, open space and other natural resources and contributed to water pollution, extinction of species, and increased competition for limited water resources.
- Construction of vast amount of surfaces, such as roads and rooftops lead to degradation of water quality by increasing surface runoff, altering regular stream flow and watershed hydrology, reducing groundwater recharge, and increasing stream sedimentation.
- Urban water availability is constrained by high water use and limited transfers from agriculture.
- Water prices are much higher as scarcity increases.

Response Packages

Initial test response packages were developed to capture a range of management strategies. They should not be seen as what will be implemented but used as a basis for identifying short, medium, and long term recommendations. A detailed work plan to be prepared during Phase 2 will identify specific options within each strategy for each of the response packages for future evaluation. This process will help identify data and analytical tools needed for each response package. It is recognized that qualitative approaches may be needed where there may not be sufficient data or adequate tools to quantify all costs or benefits.

It is important to note that under scenario planning, the evaluation is an iterative process where other response packages or ensembles can be developed by combining various strategies from each of the four response packages as results from the analytical work become known.

The following summarizes response packages that will be developed in Phase 2 of the work plan and evaluated in Phase 3. (See Section, Next Steps for Using Analytical Tools Including Short-term and Long-term Work Plan)

Response Package 1— Current Response Strategies

This package represents those strategies that most agencies are currently implementing. These strategies, packaged together, are being implemented by state, regional, and local organizations. They are technically and institutionally feasible, they make sense for the environment, they are economical, and do not raise significant equity issues.

Test Purpose: Recognizing that agencies can continue to implement those strategies that are supported by stakeholders, testing this response will determine how effective this package will be in meeting future water needs. The needs will be determined in Phase 2 for each of the alternative futures.

Goal: The goal of this package is to emphasize maximum implementation of current strategies supported by stakeholders.

Strategies: This response package would include options from strategies identified in this category that are widely supported by stakeholder groups. It consists of options that are proven effective, and are currently in use. The costs and benefits are generally known and can be quantified or acceptable qualitatively to justify implementation. This response package would also include options from strategies that stakeholders widely support but somewhat conditional based on the uncertainties of costs and benefits to justify implementation. An example would be the amount of urban water conservation that could be achieved using acceptable new technologies.

Discussion of Response Package 1 Strategies

Agricultural water use efficiency can benefit farmers by increasing net profit, reducing water applied, reducing groundwater overdraft, increasing yield, improving crop quality, improving districts ability to meet customer demands and reduce water losses, improving water quality, reducing drainage and surface runoff, increasing stream flows and improving temperature and timing, and potentially profiting from the sale of conserved water. Funding, implementation, education and motivation, innovation, dry year considerations, measurement, and planning and evaluation are obstacles to improvement. Farmers who implement efficiency measures not funded by the state incur costs.

Aquifer remediation to be added when narrative completed

Conjunctive management could increase average annual water deliveries and increase new storage through reoperation of existing groundwater storage and recharging water into currently empty groundwater storage space. It can stop land subsidence. Conjunctive management can improve water quality and benefit the environment when recharge basins are designed to be compatible with wildlife habitat.

Desalination to be added when narrative completed

Drinking water treatment and distribution can improve drinking water quality, which could directly improve the health of Californians, improve their standard of living and reduce the burden of costs associated with illnesses related to poor water quality.

Economic Incentives Policy to be added when narrative completed

Ecosystem restoration to be added when narrative completed

Matching water quality to use is an integral part of water management for agricultural and in-stream uses. Matching high quality source waters can reduce the levels of pollutants that cause health concerns in drinking water. Water agencies can experience improved treated water quality and supply reliability.

Pollution prevention can improve water quality for all beneficial uses by protecting water at its source. It can reduce non-point sources from urban and agricultural runoff and point source discharges. Pollution prevention approach to water quality is more cost-effective than end-of-the-pipe treatment of wastes.

Precipitation enhancement can increase water supply or hydroelectric power generation. Precipitation enhancement can increase costs of snow removal in mountain areas, and cloud seeding raises concerns about the long term toxic effects of silver, used for cloud seeding.

Recharge area protection can improve groundwater quality and ensure replenishment of groundwater supplies with good quality water ensuring a sustainable and usable water supply. Recharge area protection can limit development on recharge areas.

Recycled municipal water can provide additional reliable local sources of water for agriculture, reduce the discharge of pollutants to water bodies, provide a secure water supply during drought periods, and spare high quality potable water from irrigation.

Urban land use management can improve water quality by decreasing surface runoff, increasing groundwater recharge, decreasing stream sedimentation, and decreasing dangers of flooding by reducing impervious surfaces. Resource efficient development requires less water and minimizes pollution of surface water and groundwater. Compact, mixed-use development can reduce water demand with moderate increases in density.

Urban runoff management reduces nonpoint source water pollution and improves flood protection. Runoff management might also improve or increase water supply through groundwater recharge, groundwater quality, wildlife habitat, parks, and open space.

Urban water use efficiency lowers demand, offers the opportunity to cost-effectively stretch existing water supplies, and avoids cost of new supply construction. Urban water use efficiency can reduce amount of energy required to treat water.

Watershed management to be added when narrative is finished

Water transfers can increase flexibility in the water management system. Transfers can create controversy regarding the effects on water users, water quality, and fish and wildlife. Transfers raise issues regarding public trustee agencies' ability to monitor the implications to public trust responsibilities. Water transfers can result in third party costs that are difficult to quantify, such as increasing the salinity of groundwater. Because most transfers come from agriculture, transfers can negatively affect agricultural productivity and economic benefits although studies indicate that some transfers could occur as a result of crop idling without dramatically affecting local economies. Water transfers can provide economic benefits to sellers, but not necessarily to the whole area. Transfers can affect vulnerable populations who work in agricultural production. Transfers that increase groundwater pumping raise concerns over groundwater overdraft and the long-term sustainability of groundwater resources.

Working Lands Management (to be added when narrative is complete)

(Note: Each of the following packages will have a discussion of strategies section developed for Volume 1; detailed discussions can be reserved for the Reference Guide or the Work Plan developed during Phase 2)

Planning for Extreme and Prolonged Drought Conditions

Water managers today use hydrologic records of the past century to estimate how climatic conditions would affect future water availability and water needs. Planners take into account the normal fluctuations of wet and dry years in allocating deliveries from reservoirs and in determining how much water will be provided from other sources. Because the state has also experienced extreme and prolonged droughts, the most recent one occurring from 1987 to 1992, many local water agencies have developed drought contingency plans for such rare but extreme conditions that can result in significant socio economic and environmental impacts. The State has provided drought assistance to local water agencies and homeowners with the implementation of Proposition 50, Water Security, Clean Drinking Water, Coastal and Beach Protection Act of 2002.

Since the last drought (1987-1992) following notable changes have occurred that would change the demand and supply. Population of California has increased by more than 6 million by year 2001 which will cause additional stress on the available water supply while completion of construction of Coastal Aqueduct (Department of Warer Resurces), Morongo basin pipelines (Mojave Water Agency), Diamond Valley Lake (Metropolitan Water district), Los Vaqueros Reservoir (Contra Costa Water District) and five large scale groundwater recharge/storage projects should add flexibility in operating the water system. Planers should take in to account these conditions when planning for another prolonged drought.

Historical Perspective

The most severe recorded drought occurred in 1976-1997. Two consecutive years with little precipitation (4th driest and the driest year in the recorded history) left California with record low storage in its surface reservoirs and groundwater levels dangerously lowered. Socio economic and environmental impacts were very severe during these extreme drought conditions. The total loss due to the drought during these two years exceeded \$ 2.5 billion (\$6.5 billion at today's cost).

The most recent prolonged drought lasted 6 years from 1987-1992. During the first 5 years of the drought, in San Joaquin valley the groundwater extractions exceeded the recharge by 11 million acre-feet which caused increased land subsidence in some areas. DWR studies indicate that in 1990-92, the drought resulted in reduced gross revenues of about \$670 million to California agriculture. Energy utilities were forced to substitute hydroelectric power with more costly fossil-fuel generation at an estimated statewide cost of \$500 million in 1991. The drought also adversely affected snow-related recreation businesses. Some studies suggest as much as an \$85-million loss for snow-related recreation businesses during the winter of 1990-91.

Drought Contingency Planning

Several drought contingency planning reports are already published at state and regional levels, some of which as a result of legislature. Three bills enacted by the Legislature to improve water supply planning processes at the local level became effective January 1, 2002. In general, the new laws are intended to improve the assessment of water supplies during the local planning process before land use projects that depend on water are approved. The new laws require the verification of sufficient water supplies as a

condition for approving developments, and they compel urban water suppliers to provide more information on the reliability of groundwater if used as a supply. Normal and drought year conditions are specified in the law when evaluating water supply reliability.

SB 221 (Bus. and Prof. Code, § 11010 as amended; Gov. Code, § 65867.5 as amended; Gov. Code, §§ 66455.3 and 66473.7) prohibits approval of subdivisions consisting of more than 500 dwelling units unless there is verification of sufficient water supplies for the project from the applicable water supplier(s). This requirement also applies to increases of 10 percent or more of service connections for public water systems with less than 500 service connections. The law defines criteria for determining "sufficient water supply, such as using normal, single-dry, and multiple-dry year hydrology and identifying the amount of water that the supplier can reasonably rely on to meet existing and future planned uses. Rights to extract additional groundwater must be substantiated if used for the project.

SB 610 (Water Code, §§ 10631, 10656, 10910, 10911, 10912, and 10915 as amended; Pub. Resources Code, § 21151.9 as amended) and AB 901 (Water Code, §§ 10610.2 and 10631 as amended; Water Code § 10634) make changes to the Urban Water Management Planning Act to require additional information in Urban Water Management Plans (UWMP) if groundwater is identified as a source available to the supplier. Required information includes a copy of any groundwater management plan adopted by the supplier, proof that the developer or agency has rights to the groundwater, a copy of the adjudication order or decree for adjudicated basins, and if not adjudicated, whether the basin has been identified as being overdrafted or projected to be overdrafted in the most current DWR publication on the basin. If the basin is in overdraft, the UWMP must include current efforts to eliminate any long-term overdraft. A key provision in SB 610 requires that any project subject to the California Environmental Quality Act supplied with water from a public water system be provided a water supply assessment, except as specified in the law. AB 901 requires the plan to include information relating to the quality of existing sources of water available to an urban water supplier over given periods and include the manner in which water quality affects water management strategies and supply reliability.

California voters approved the Water Security, Clean Drinking Water, Coastal and Beach Protection Act of 2002 (Proposition 50; Water Code, § 79500 et seq.) in the November 2002 elections. The initiative provides for more than \$3.4 billion of funding, subject to appropriation by the Legislature, for a number of land protection and water management activities. Several chapters of Proposition 50 allocate funds for specified water supply and water quality projects, including Chapter 3 Water Security. It provides \$50 million to protect State, local and regional drinking water systems from terrorist attack or deliberate acts of destruction or degradation.

Local and Regional Efforts

The urban Water Management Act requires that each urban water agency which serves more than 3,000 people or 3,000 acre-feet per year, to prepare its own water management plan once in every five years. The urban water management plan includes an analysis and a contingency plan for water supply reliability in face of a severe drought which includes up to 50 percent reduction in water supply. Water management plans lay out shortage contingency scenarios that districts will use as guide lines when reducing demand and augmenting short term supply. Long and short term conservation measures,

recycling water, water transfers, short term sources of water, and long term storage including conjunctive use are some of the tools that water districts use to plan against a multi year drought

State Efforts

The Governor's Advisory Drought Planning Panel was formed in 2000 to develop a contingency plan to address the impacts of critical water shortages in California. The panel formed with the recognition that critical water shortages may severely impact the health, welfare, and economy of California. In its July 2000 report, "Preparing for California's Next Drought", the Department reviewed items for near-term drought planning, putting California's conditions today into perspective with experiences gained in the 1987-92 drought. Major findings of the report focused on the characterization of drought conditions as a gradual phenomenon and as a function of impacts on water users. The report also addressed the vulnerability of existing water users based on past droughts, and a discussion of current actions that affect drought preparedness planning.

As part of a five year planning program to implement specific actions of the CALFED Bay-Delta Program, a Governor's Drought Panel, in its December 2000 report, "The Critical Water Shortages Contingency Plan", made recommendations for actions that the State government could take to reduce the impacts of critical water shortages. The recommendations included a critical water shortage reduction marketing program to facilitate intra-regional, short term, and dry year transfers, financial and planning assistance to local agencies for drought-related response activities, and assistance to small water Systems and homeowners in rural counties. The work on these programs started early 2002 and is still ongoing through bond measures Proposition 13 (March 2000) and Proposition 50 (November 2002).

Governor's Advisory Drought Planning Panel (2000)

The CALFED Record of Decision (August 2000) called for the Governor to convene a Panel, chaired by the Director of DWR, to develop a contingency plan for reducing impacts of critical water shortages in the next several years while the actions identified in CALFED's Stage 1 were being planned and implemented. The Governor's Advisory Drought Planning Panel identified a variety of physical, regulatory, and institutional challenges to effective water management during times of critical water shortages.

The Panel intended the following recommendations to be statewide in scope, applying to any areas of the State that may benefit from them. Nothing in the recommendations is intended to limit their geographical scope to CALFED study areas. The Panel did not intend that its recommendations duplicate actions already scheduled for early implementation in the ROD, but rather suggests that ROD actions and the Panel's recommended actions be coordinated, as much as possible, to maximize their benefits.

- A. Critical Water Shortage Reduction Marketing Program. The Panel recognized that the CALFED agencies were tasked with streamlining the water transfer process. In addition to the CALFED actions, the Panel recommended that DWR implement a Critical Water Shortage Reduction Marketing Program. The program would be operated as an as-needed water purchasing and allocation program using a three-tiered methodology. Tier 1 would consist of water shortage preparedness activities undertaken by State and local agencies. Tier 2 would consist of purchasing options and allocating water to communities that have maximized their own resources. Tier 3 would be implemented during a water shortage emergency and would include continued implementation of Tier 2 actions, plus extraordinary measures needed to protect public health and safety, such as State

financial assistance for water hauling, pipeline construction, or well drilling. DWR would acquire options to purchase water from willing sellers and would exercise the options as needed to make water available for sale to water users experiencing critical water shortages. The Panel further recommended that the Governor propose, and that the Legislature provide, a General Fund appropriation for preparing a programmatic EIR for Critical Water Shortage Reduction Marketing Program.

- B. Assistance to Small Water Systems and Homeowners in Rural Counties. The Panel recommended that DWR develop a technical assistance and education program targeted at rural homeowners and small domestic water systems relying on self-supplied groundwater, to be implemented in consultation with rural county environmental health departments. The Panel further recommended that the Governor propose, and that the Legislature provide, an annual appropriation of at least \$1.5 million from the State General Fund to support this program. The program would include workshops to educate homeowners; a website containing information on State and county well construction requirements, sources of groundwater level and well yield data; and requirements for informing potential home buyers of the groundwater and well conditions and risks.
- C. Local Agency Groundwater Programs. The Panel recommended that DWR establish an AB 3030 technical assistance program, following the process established in Water Code Section 10795 et seq. The Panel further recommended that the Governor propose, and that the Legislature provide, an appropriation from the State General Fund of at least \$5 million per year to implement the program. In addition, the Panel also recommended that the Governor propose, and that the Legislature provide, an appropriation of \$1 million annually from the State General Fund to provide for ongoing statewide groundwater data collection and compilation (including geohydrologic and water quality data), and that DWR publish this information every five years as updates to Bulletin 118.
- D. Local Agency Integrated Water Management Plans. The Panel recommended that DWR and other CALFED agencies work in partnership with local water agencies to assist them in developing plans to facilitate integrated management of supplies for agricultural, urban, and environmental purposes. The Panel further recommended that DWR provide financial assistance, in the amount of at least \$2 million per year from a combination of General Fund, Proposition 204, or Proposition 13 monies to local agencies for preparing integrated water management plans.
- E. Drought-Related Research and Public Outreach Activities. The Panel recommended that DWR identify and seek funding for research in the areas of long-range weather forecasting, global climate change, and paleoclimatology. The Panel recommended that DWR compile existing local agency drought watch indices and develop regional hydrologic drought indices for watersheds important to statewide water supply conditions and watersheds supporting significant urban and agricultural development. The Panel also recommended that DWR develop a public outreach program to stress the need for drought preparedness, building on the recommendations of the May 2000 report of the National Drought Policy Commission.
- F. Accelerate Proposition 13 Financial Assistance to Local Agencies. The Panel urged the Governor to take all possible actions to ensure rapid disbursement of Proposition 13 funds, including out-of-State recruitment for new staff, statutory waiver of Water Code requirements for review of DWR rules and regulations by the California Water Commission, and expediting or statutory waiver of Office of Administrative Law review of rules and regulations. The Panel further recommended that bond monies applicable to CALFED actions be budgeted as quickly as possible, and that DWR maximize use of grants, rather than capitalization loans, to bring local agencies up to the base level of efficiency contemplated in the CALFED ROD.

DWR has implemented many individual actions aimed at meeting these recommendations. A few examples include:

Operated a dry year water purchasing program

- Held educational workshops for private well owners
- Convened the Small Water System Drought Preparedness Advisory Committee
- Conducted a competitive selection process for grants for preparation of groundwater management plans
- Installed production wells in the Klamath Basin
- Installed monitoring wells in Mendocino County
- Developed a drought preparedness web site
- Co-sponsored an academic conference on droughts

Responding to Future Droughts

In planning for future water supplies and needs, the hydrology of the past century may not be a reasonable measure of the climate in Northern California. The flow record available for California is rather short for determining hydrologic risks, extending back only about 100 years with mostly qualitative information perhaps for another 100 years. Past tree ring studies have shown extensive dry periods far exceeding the 6 year maximum that was recorded in the last century. For potential significant reductions to the Sierra snow pack from climate change as it may affect current hydrology is discussed under global climate change.

Planning Framework for Water Plan Update

In accordance and guided by the statutes of the Water Code, the Department of Water Resources (DWR) and an active 65-member advisory committee with input from a 320-member Extended Review Forum, prepared this water plan update by first developing a new planning framework to increase its utility and usefulness. The advisory committee is composed of representatives of agriculture, urban water districts, businesses, environmentalists, Native Americans, environmental justice advocates, cities, counties, federal and State agencies, the California Bay Delta Authority, academia, and different regions of the State.

DWR, the State department responsible for preparing water plan updates, and the advisory committee believe that the new framework is one of the significant accomplishments of this water plan update and should serve as the cornerstone for future updates because the framework (1) considerably expands public involvement and access to the State's water planning process; (2) seeks collaborative recommendations that are more robust, have greater longevity, and are more likely to be adopted by the Governor's Office, Legislature, and State, federal, and local agencies and governments, and resource managers; and (3) results in a strategic plan, which is a living document with stated goals, objectives, and implementation plan, including progress tracking, indicators and reports.

The new planning framework consists of:

- Collaborative planning process,
- Comprehensive way for describing current and future water supplies, uses and management (Water Portfolios with over 80 categories) using actual data (not trend-based) for recent yet different water year types, namely 1998 (wet), 2000 (average), and 2001 (drier),
- Detailed reports on each of the regions of the State,
- Multiple scenarios for plausible futures (not a single "likely" future) to identify and minimize future uncertainties and risks, and
- Many diverse resource management strategies to meet future water demands while sustaining our resource base and economy.

The public review draft of the California Water Plan Update 2003 marks the end of the first of a three-phase work plan for completing update 2003 and beginning update 2008. Important elements of the new framework, notably future scenarios for regional planning and multiyear drought analysis, will be completed in subsequent phases in 2004 and 2005. DWR and the advisory committee developed the phased work plan to balance stakeholder interest to take the time required to implement the new framework with the need for the State to provide the next water plan update in a timely way. The phased work plan was needed because (1) DWR and the advisory committee want to more fully implement the new framework; (2) there is yet to be stakeholder agreement on the data, analytical tools, and methods that DWR will use to quantify and analyze multiple regional scenarios for 2030, including multiyear droughts and optional management responses; (3) DWR's schedule for conducting data analyses was delayed by the time needed to develop the new framework; and (4) DWR's budget and staff resources were reduced during this update cycle.

This update recognizes the vital importance of working with key stakeholders to define issues, identify potential approaches, and evaluate planning steps. Since January 2001 DWR and an advisory committee representing critical sectors with an interest in water management have worked to shape the new planning

framework and strategic planning process. Using large group meetings held roughly every six weeks for three years, more frequent smaller work groups and workshops, and many public briefings, DWR sought a broadly informed and consensus-seeking process. Advisory committee members provided the Department with substantial suggestions and recommendations on all aspects of the water plan update 2003.

Collaboration Statistics

| Type of Meeting | Meetings | Person hours |
|--|----------|--------------|
| Advisory committee | 32 | 9,855 |
| Workshops | 32 | 2,260 |
| Work groups | 62 | 4,271 |
| Extended review forum & organizational briefings | 16 | 426 |
| Tribal outreach | 3 | Pending |
| Totals | 145 | 16,812 |

The role of the advisory committee was to provide diverse perspectives and to the fullest extent possible meet the interests of all Californians and the natural environment. The group was called upon to provide DWR with suggestions and conclusions on every aspect of the water plan update, including developing goals and strategies for water management in California.

The advisory committee strove to reach consensus on the purpose, content, and process of the water plan update. The support of the entire group was always initially sought; however, where time did not permit the resolution of all fundamental concerns with a proposal, the facilitation team captured the range of support and opposition to the proposal in its final wording. Information was then communicated to DWR for consideration and final decision. Those suggestions approaching consensus received the highest possible consideration for incorporation into the update.

As part of their membership obligations, advisory committee members periodically briefed their constituencies on key developments. Members relayed comments received during these briefings to DWR. The briefing process helped ensure two-way communication between members and their organizations. In addition, briefings formally expanded the dialogue beyond the precincts of the advisory committee meeting room into a wider audience of potential users of California Water Plan Update 2003.

To create a fair, open and transparent process, the California State University Sacramento, Center for Collaborative Policy (Center) provided impartial third party facilitation and mediation design, implementation, and refinement for the consensus-seeking process. The center ensured advisory committee members' interests, views, and opinions were thoughtfully considered and advisory committee activities were governed by its own operating guidelines.

In addition to the formal advisory body, an Extended Review Forum, composed of individuals with a high interest in the process attended periodic briefings and received invitations to advisory committee and work group meetings as well as updates on key developments. With more than 320 members, this group represents an even broader range of interests than the advisory committee. DWR also used other forums to engage other State, federal, and local government representatives, local water interests, the public, and

media. DWR periodically briefed the Governor’s Office, Legislature, and the Resources Agency on the process.

The Internet provided another principal venue for advisory committee work. In its efforts to create an open and transparent public process, DWR used e-government technology to set up web pages and electronic surveys, and used email correspondence and teleconferencing whenever possible. DWR posted meeting agendas, materials, and highlights, including draft copies of California Water Plan Update 2003, for all to see. DWR also posted numerical data for the water portfolios and documentation on the web site for use by advisory committee members and other interested parties.

In line with the strategic planning process, DWR conducted a customer survey with people who may use the California Water Plan to ultimately make update 2003 widely understood and useful. The survey served to expand the audience of government, private, and nonprofit entities to include land use planners, natural resources planners, environmental and social advocacy groups, business sectors (for example, agricultural, real estate, financing), professional associations, academic institutions, water planners, wholesalers and retailers, and similar individuals and groups.

The survey indicates the planning horizon for most users is 2010. The issues of interests for evaluation parallel the advisory committee’s, including water quality, cost, reliability, and environmental impacts. And major issues of concern are water quality, reliability, and land use planning.

In addition to the customer survey, the Center for Collaborative Policy conducted several stakeholder assessments with advisory committee members throughout the process. These served as feedback mechanisms for identifying issues for DWR to consider in the water plan update 2003, assessing staff progress for the work at hand, modifying meeting methods, and improving communication channels between DWR and the advisory committee and within the advisory committee.

The time taken to use a systemic approach for water planning is an investment. However, because of the current investment, future water plan updates won’t have to start from scratch in setting up advisory committees, establishing protocols or reinventing planning approaches.